Multi wavelength studies of The Galactic Center

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Plan of the Talk

1. Introduction

2. Radio, X-ray and IR studies of the galactic center(mostly from last 5 years)-

   Rough Neighbourhood ?

   Dim Black Hole – Energetic Supernova remnant
   Also Cosmic rays of Highest energies ? -

3 GC in low (INTEGRAL, EGRET) and high energy (HESS, MAGIC etc) gamma rays – Dark Matter

4 Possible (first ?) Cosmic rays source

> *a trip to the* galactic center>

Zoom in from the naked-eye view of Sagittarius to the *unique objects* hidden in the Milky Way's *rich and complicated* core.

By Angelle Tanner

Looking into our galaxy's depths. John Gleason assembled this composite image from pictures he took of the Milky Way, Lassen Volcanic National Park in California, and a star party held by his club at the park's Bumpass Hell parking lot. The small yellow box shows the

GALAXY – PRE SHAPLEY

- 1610 – Galileo first to

See stars in the MW

18^{th} Cent – Herschels

700 brighter stars – galaxy

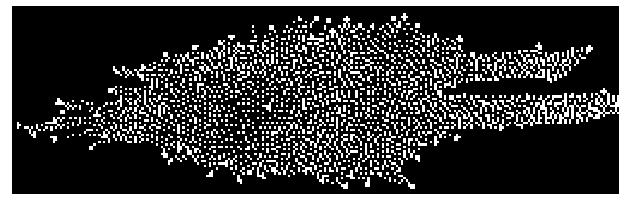
Like an irregular

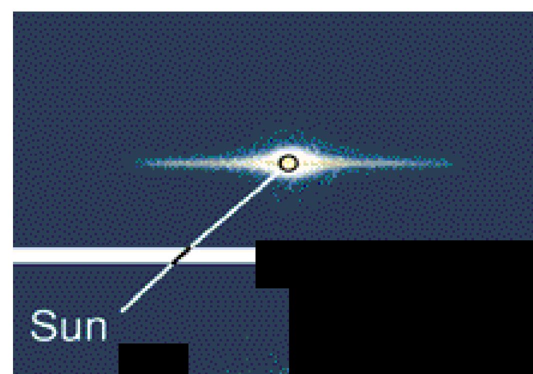
grindstone

Sun off center to left

- was not aware that
- Dust would obscure/
- Attenuate etc

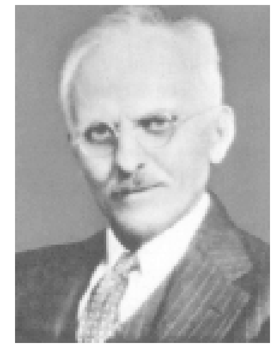
Herschels' picture





The Curtis-Shapley Debate

Shapley



Curtis

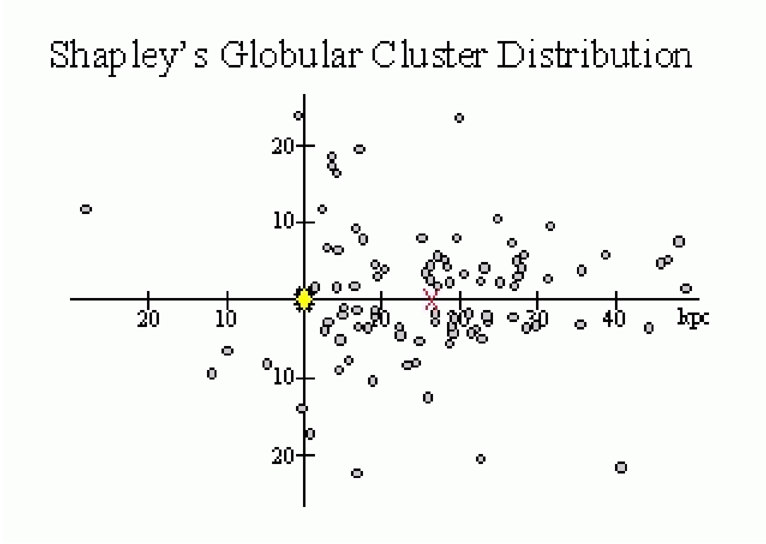
- what is the size of our galaxy?
- what is the nature of spiral nebula?

H.Shapley

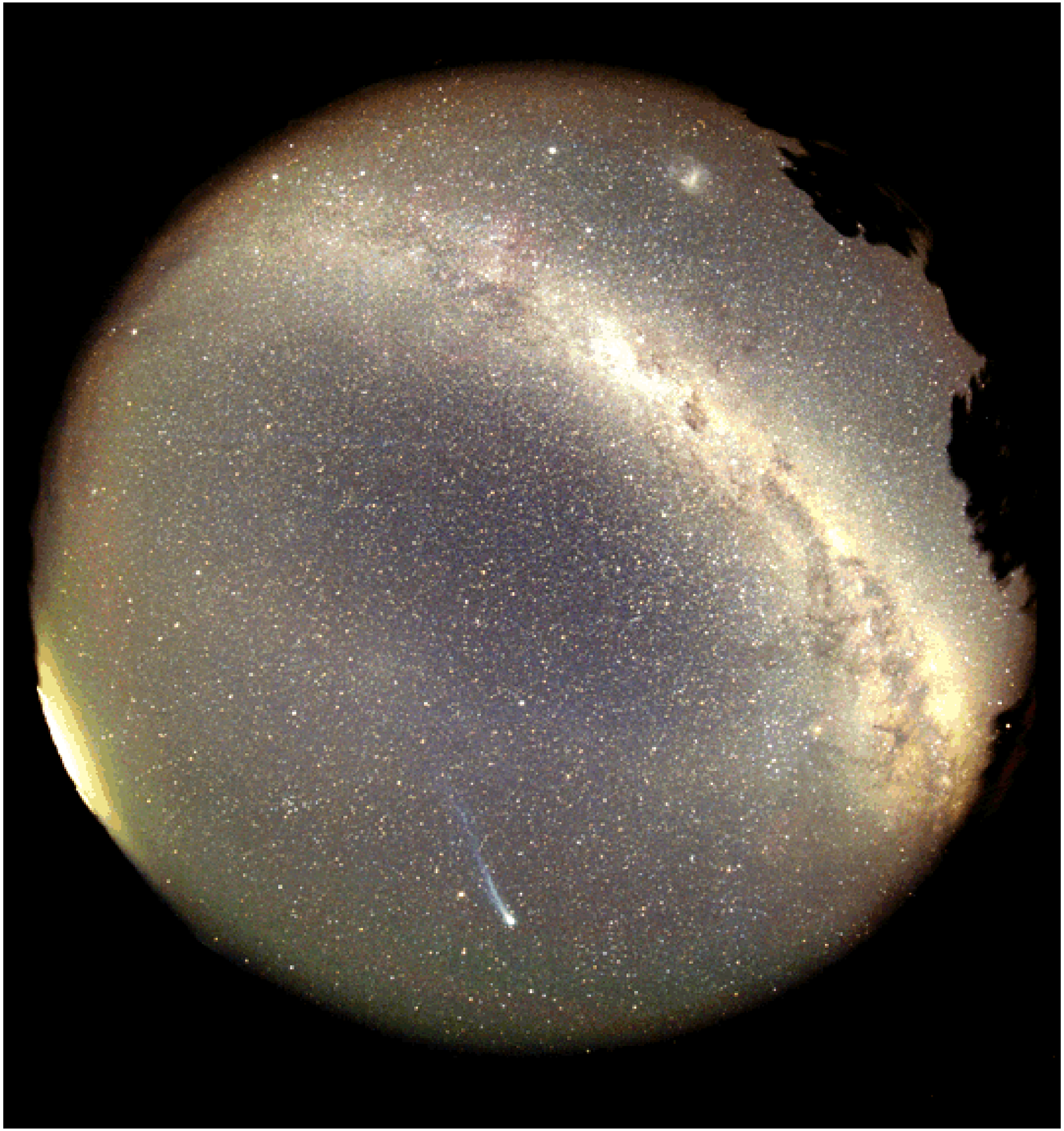
~1920

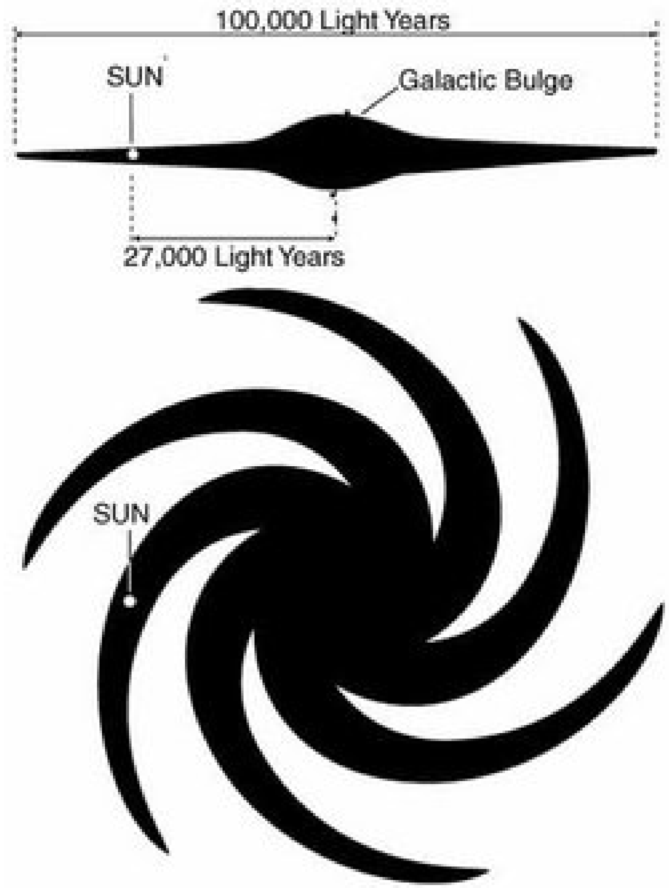
- Used Globular Clusters
- (Dense star regions) ~200 in the
- galaxy - should appear equally
- populated around center
- - But found only in one
- direction- of Sagittarius

- Shapley overestimated
- Distances 40000 lY
- Present ->26000LY
- Sun 8000 kpc from
- center



Milky way in southern hemisphere (dec=-30)




100,000 Light Years
SUN
Galactic Bulge
27,000 Light Years
SUN

Galactic Center region

10**7 stars in a region 5 ly across! (solar neighbourhood ~4 stars)

But because of dust , attenuation by a factor of 100 million (10**8)

If not the region would have the brightnes of full moon !

only one in 10**(12) optical photons reaches earth

However, the attenuation is small for other wavelengths – IR, Radio and x-gamma

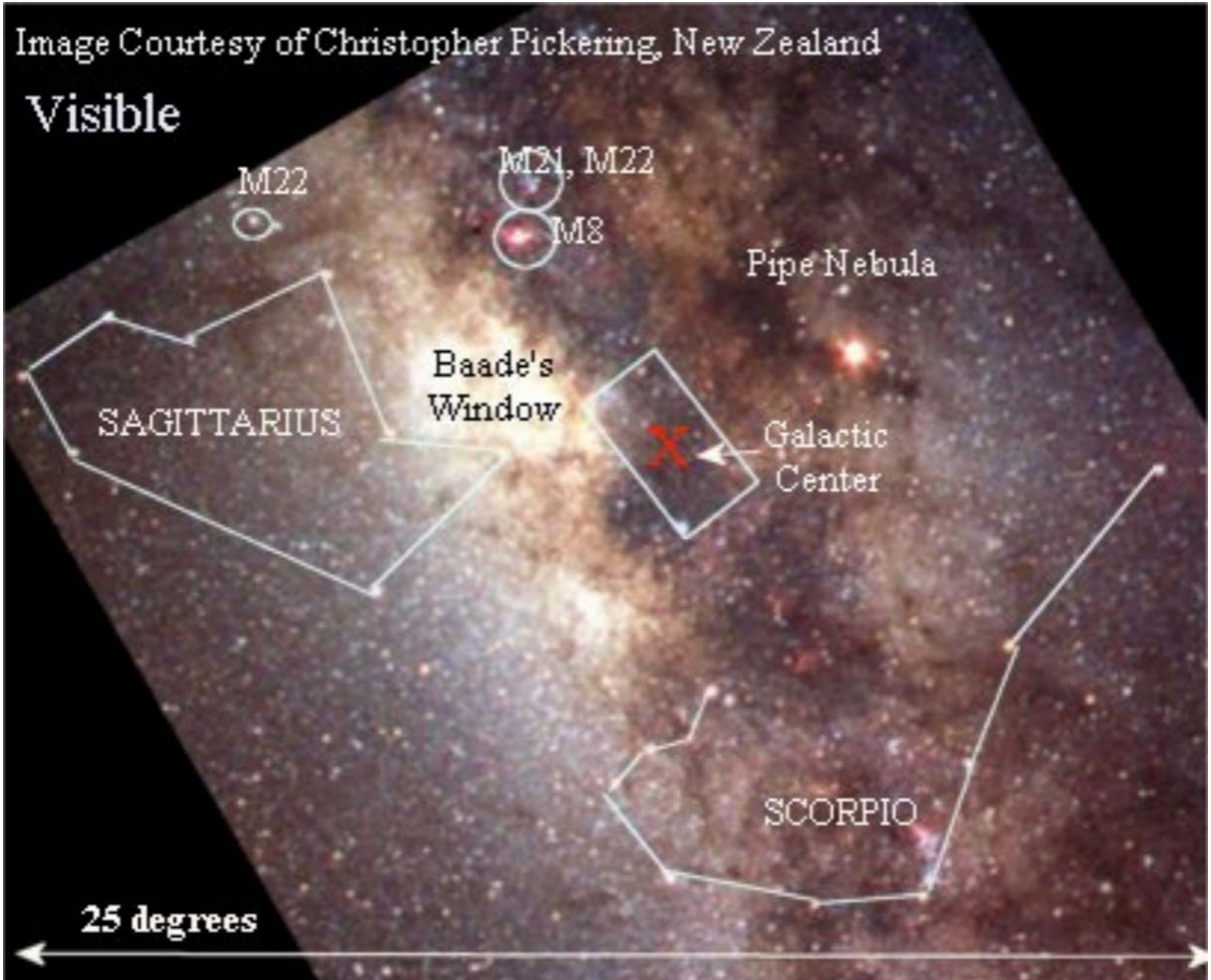


Image Courtesy of Christopher Pickering, New Zealand
Visible
M22
M21, M22
M8
Pipe Nebula
Baade's
Window
SAGITTARIUS
X
Galactic
Center
SCORPIO
25 degrees

Jansky/Geber('30s) Posible detection (poor angular resolution)

Piddington+Minnett (1951) 1210 mhz

' A new , remarkably powerful , discrete source – lies close to the maximum of galactic radiation'

McGee + Bolton (1954):

'Probable observation of the galactic nucleus at 400mhz'

Till 1960 – controversial

Shklovsky (1960) : It is definitely established

That Sag A is indeed the galactic radio nucleus !

Supermassive Black Holes must exist at the centre of active galaxies .

Even ordinary galaxies (like our own galaxy) can have such SMBH at the centre(LyndenBell+Rees)

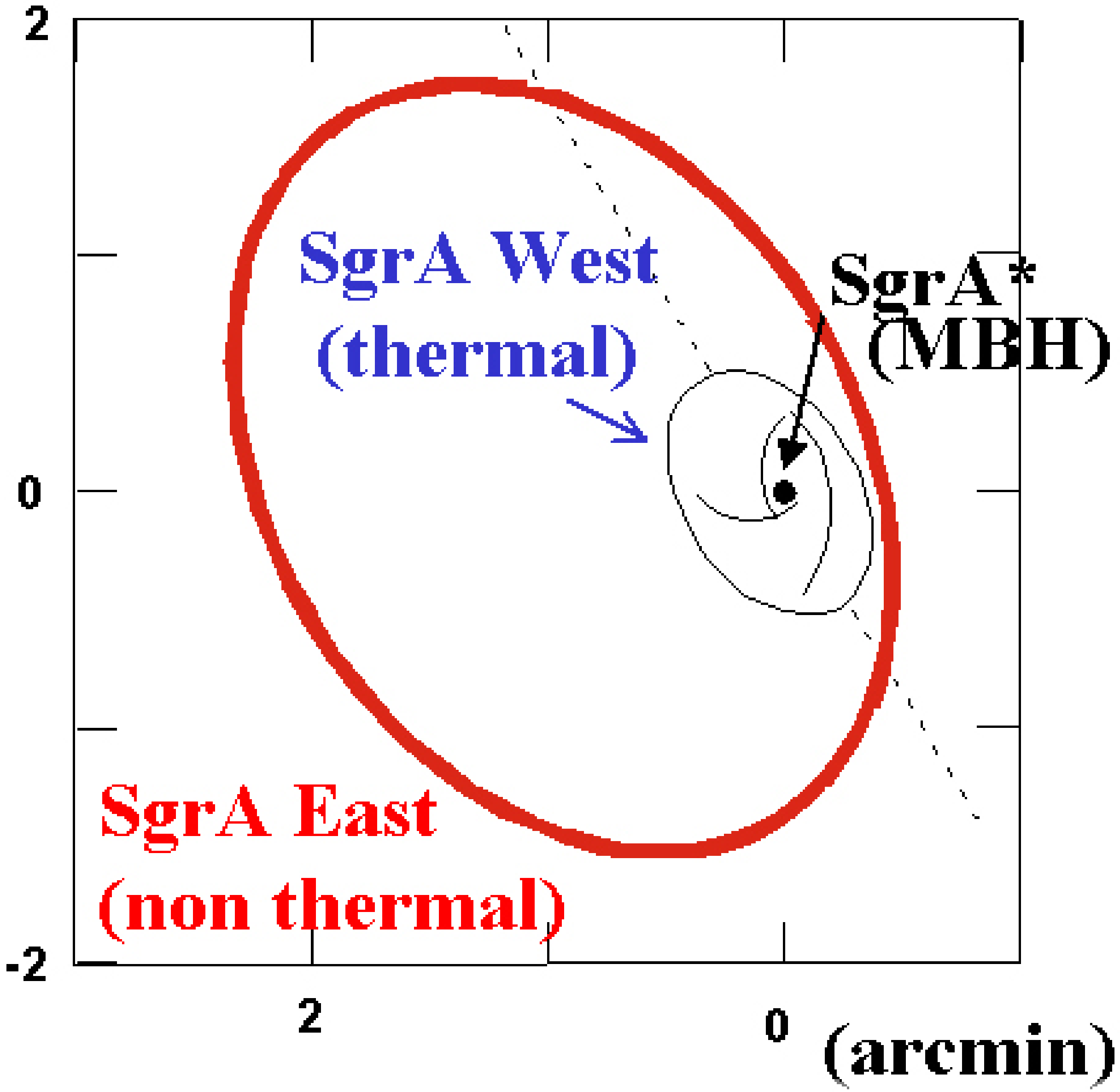
1974 Balick/Brown compact and variable radio source at the center of the galaxy – Sgr A*

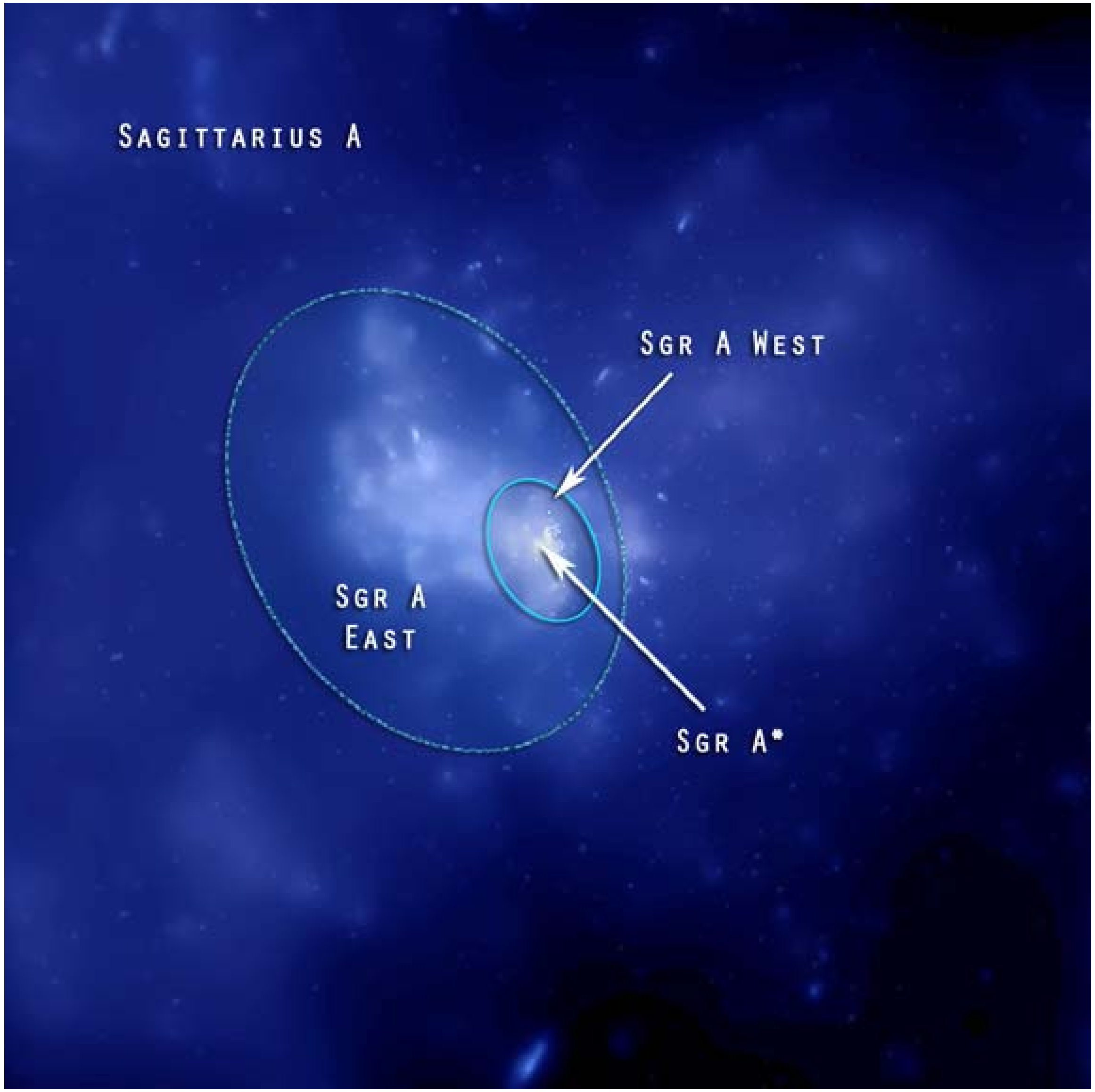
- faint quasar like

1977/1979 Spectroscopy → large Doppler shifts- large velocities –Large mass ?

1976 Shklovski – Sgr A west radio emission – very powerful source at the Galactic center -30000 solar mass BH

1977 VLBI – Sag A * low luminosity AGN
4-13 times less than other AGN


2
0
-2
2
0
(arcmin)
SgrA West
(thermal)
SgrA*
(MBH)
SgrA East
(non thermal)

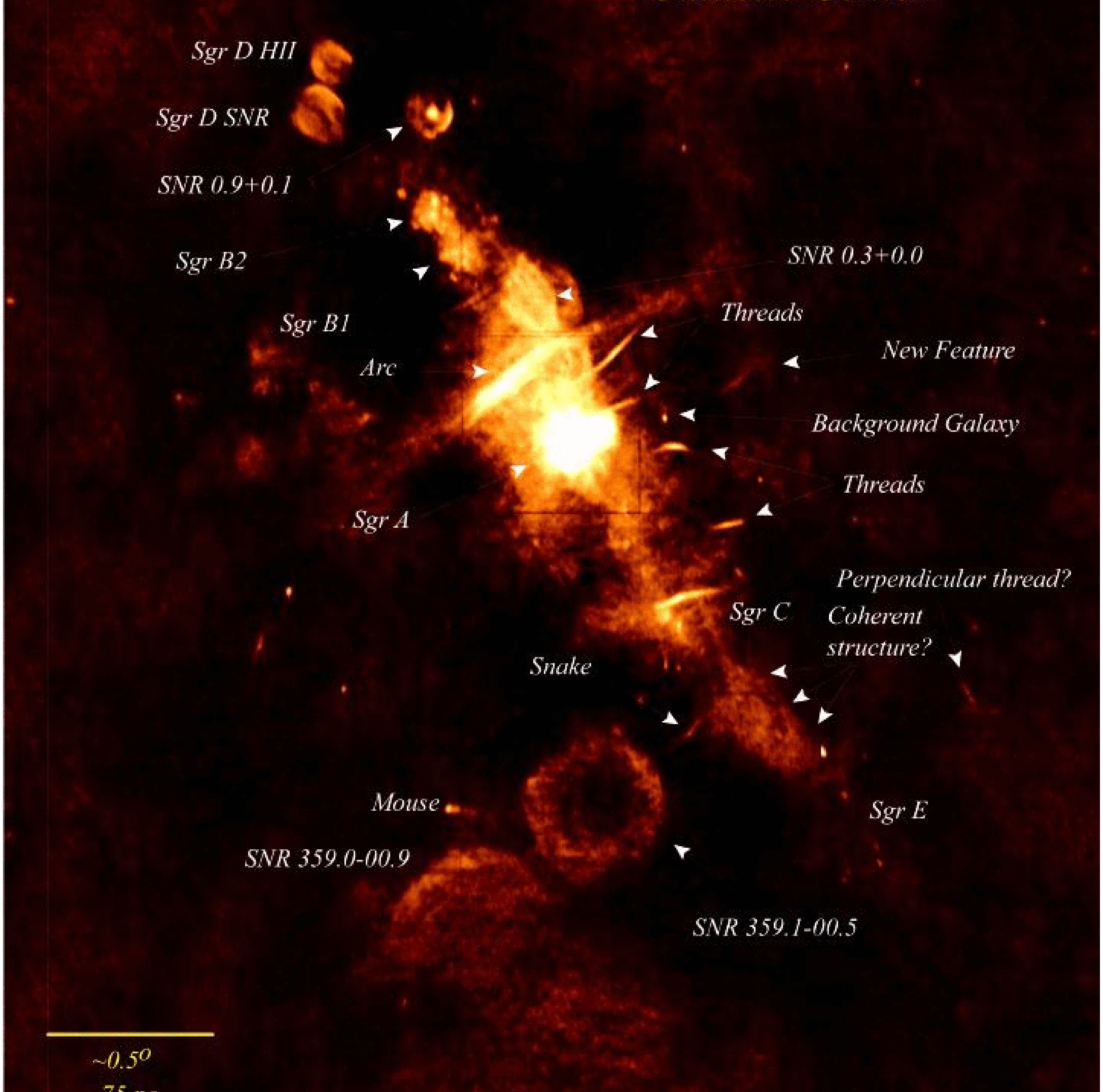


Sagittarius A
Sgr A West
Sgr A
East
Sgr A*

- **The central radio emission consists of three parts: (VLA map)**
- **Sagittarius A East: a hypernova remnant, which was produced by a violent explosion only several tens of thousands of years ago. The origin is unknown. Explanations range from a star disrupted by a black hole to a chain reaction of ordinary supernovae or even a gamma-ray burst.**
  Sagittarius A West or Minispiral: Gas and dust streamers ionized by stars and spiraling around the very center, possibly feeding the nucleus.
  Sagittarius A *: A bright and very compact radio point at the intersection of the arms of the Minispiral (dist between
- **Sgr east and A* is 2 pc)**

Sgr A* ra - 17.45.40: dec –29.00.28

Sgr a east same ra , dec = -29.00.20

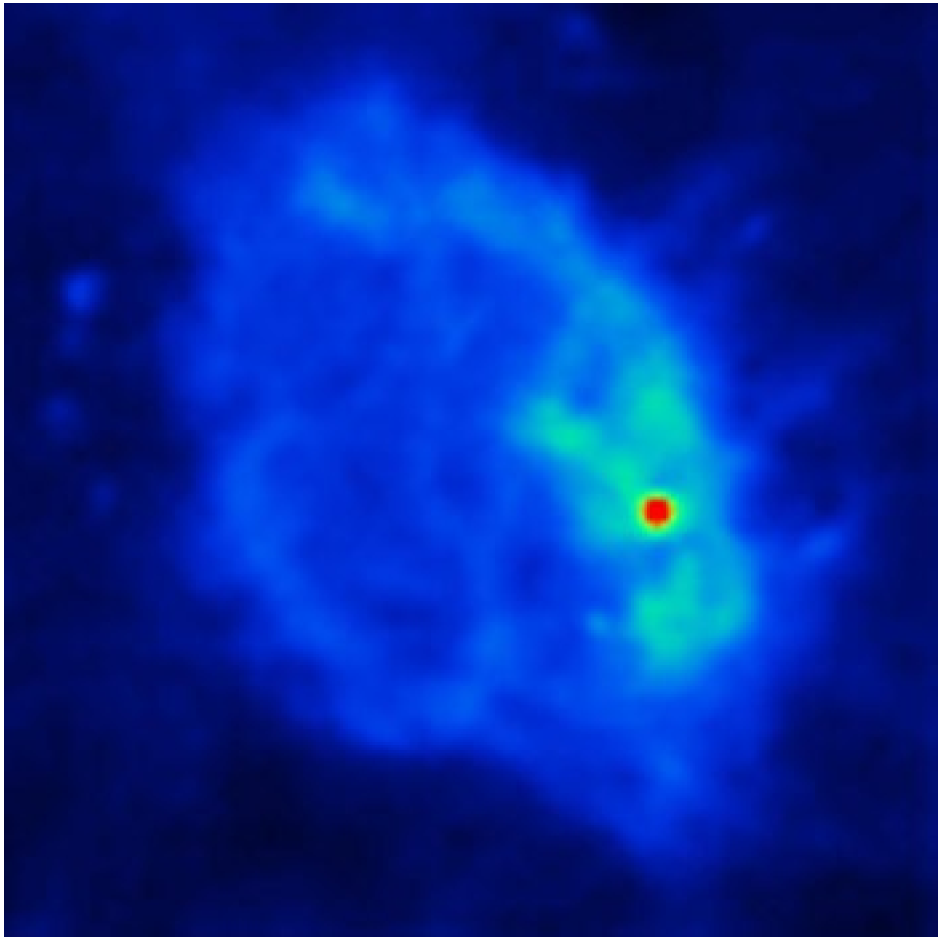

Sgr D HII
Sgr D SNR
SNR 0.9+0.1
Sgr B2
SNR 0.3+0.0
Threads
Sgr B1
New Feature
Arc
Background Galaxy
Threads
Sgr A
Perpendicular thread?
Sgr C
Coherent
structure?
Snake
Mouse
Sgr E
SNR 359.0-00.9
SNR 359.1-00.5
~0.5°

• RADIO DATA

Some stars- in the very center (the position of Sagittarius A*.) are moving very fast (~1000 kps). A huge dark mass in the center pulls them around with its gravitational force.
Using the velocities(Kepler's law)

- **The mass near Sag A* is 2.6 million times the solar mass .**
- **Vel of Sgr A* itself is very small (~20 km/sec)!**
- **Therefore it is not a star . Is this a black hole?**

Sgr A east (radio) and Sgr A *



X-RAY DATA

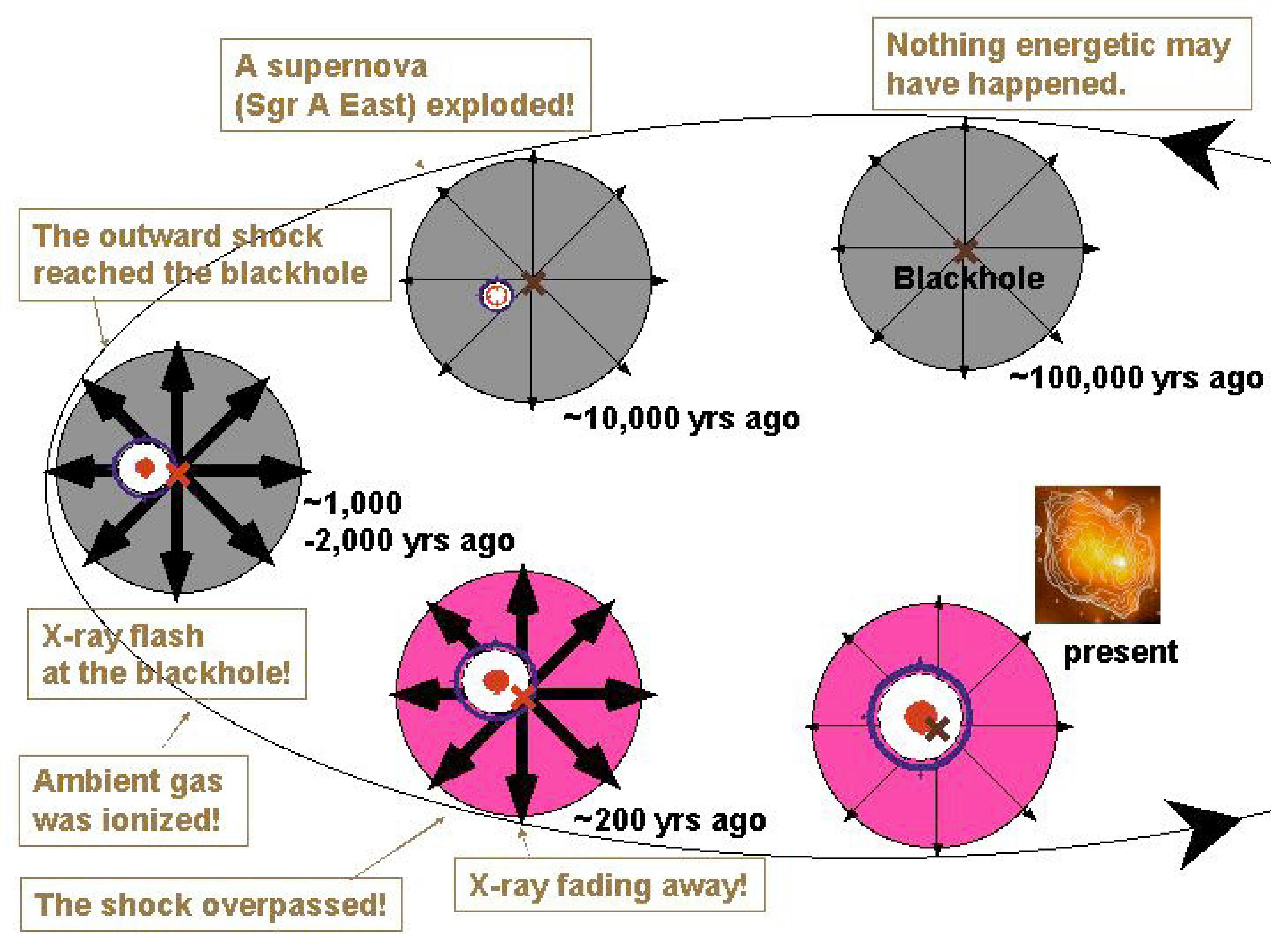
- Before Chandra, no sensitivity
- In 2000 MIT found a faint (5 times less) x-ray source at Sgr A*
- Dearth of matter for BH ? Or BH rejecting matter ?
- 2001 – an intense flare x 45 times(equ. Of comet mass falling)
- In the middle of the flare X-ray intensity dropped 5 times
- Thus fluctuations >> size small – extant < the dia of mercury orbit – 16 million km across

Sagittarius East

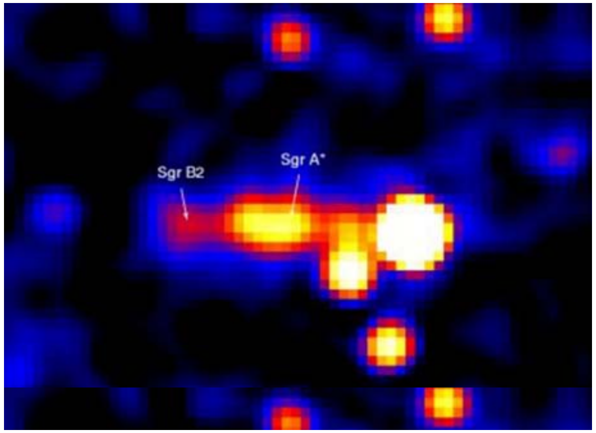
one of the largest supernova remnants known
Strong magnetic field ,
Highly enriched (X 4-5 sol.syst) in Heavy elements
Age ~ 100,000 - 10,000 years ago.
The energy required ~ 50 times greater than the most powerful supernova explosion. S
Some theorize that Sagittarius East was created when a star approached within 50 million miles of the central black hole and was torn apart by the strong gravity.

Connection between Sgr A (East) and Sag A*

- ~ 10000 yrs ago – Low mass progenitor– expanding gas etc takes away the matter near BH
  Starved BH – A SNR regulating a SMBH
- Thus 3 million solar mass in a small region !!
  ~2003 – more flares – jet from BH



A supernova
(Sgr A East) exploded!
Nothing energetic may
have happened.
The outward shock
reached the blackhole
Blackhole
~100,000 yrs ago
~10,000 yrs ago
~1,000
-2,000 yrs ago
X-ray flash
at the blackhole!
present
Ambient gas
was ionized!
~200 yrs ago
The shock overpassed!
X-ray fading away!



Results from INTEGRAL (hard x-ray/lo gamma ray) Jan 2005

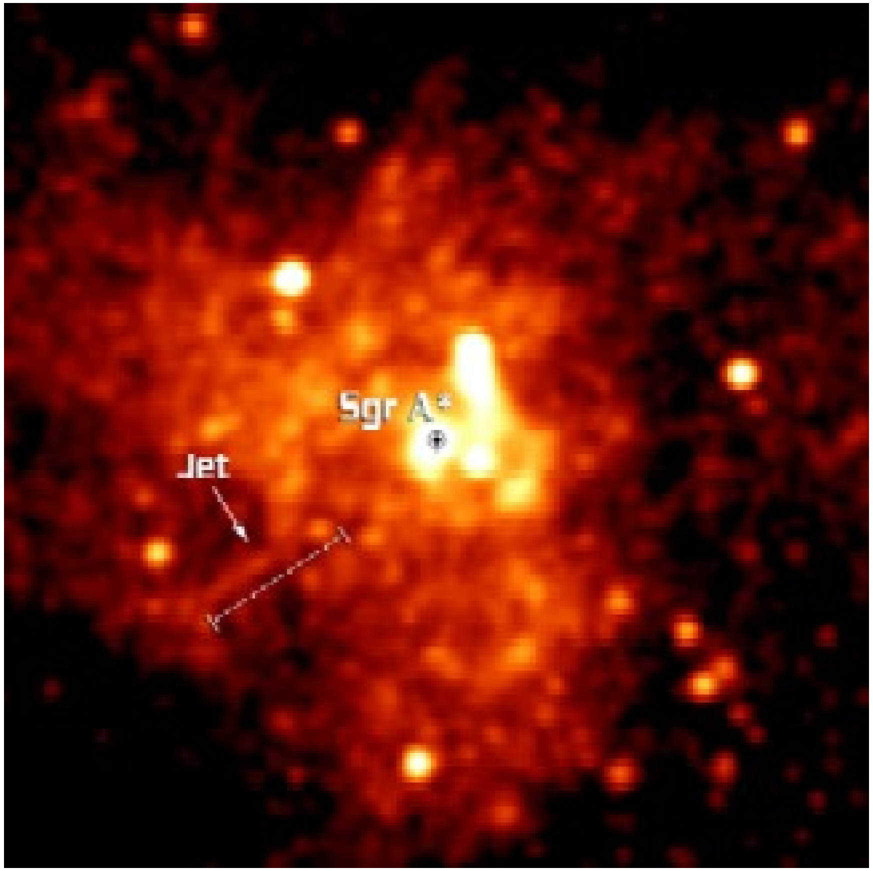
Sgr A* - B2 sep 350 ly

Mol. Cloud Sgr B2 is being exposed to Gamma rays emitted 350 years ago from SGR A*-> is now reemitting

X-ray echo of Sgr A* activity in the past

More active in the past !

Sgr A* and –xray jet



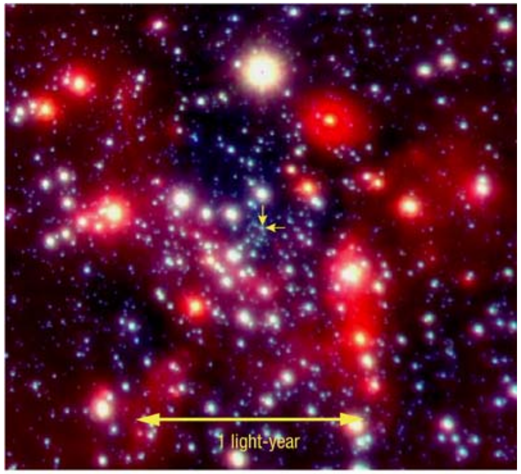
Near IR Data

KEK/UCLA/MPIEP

1995 – 2004 Orbits of several stars studied – within 1 “ x 1” of galactic centre – reveals presence of a SMBH

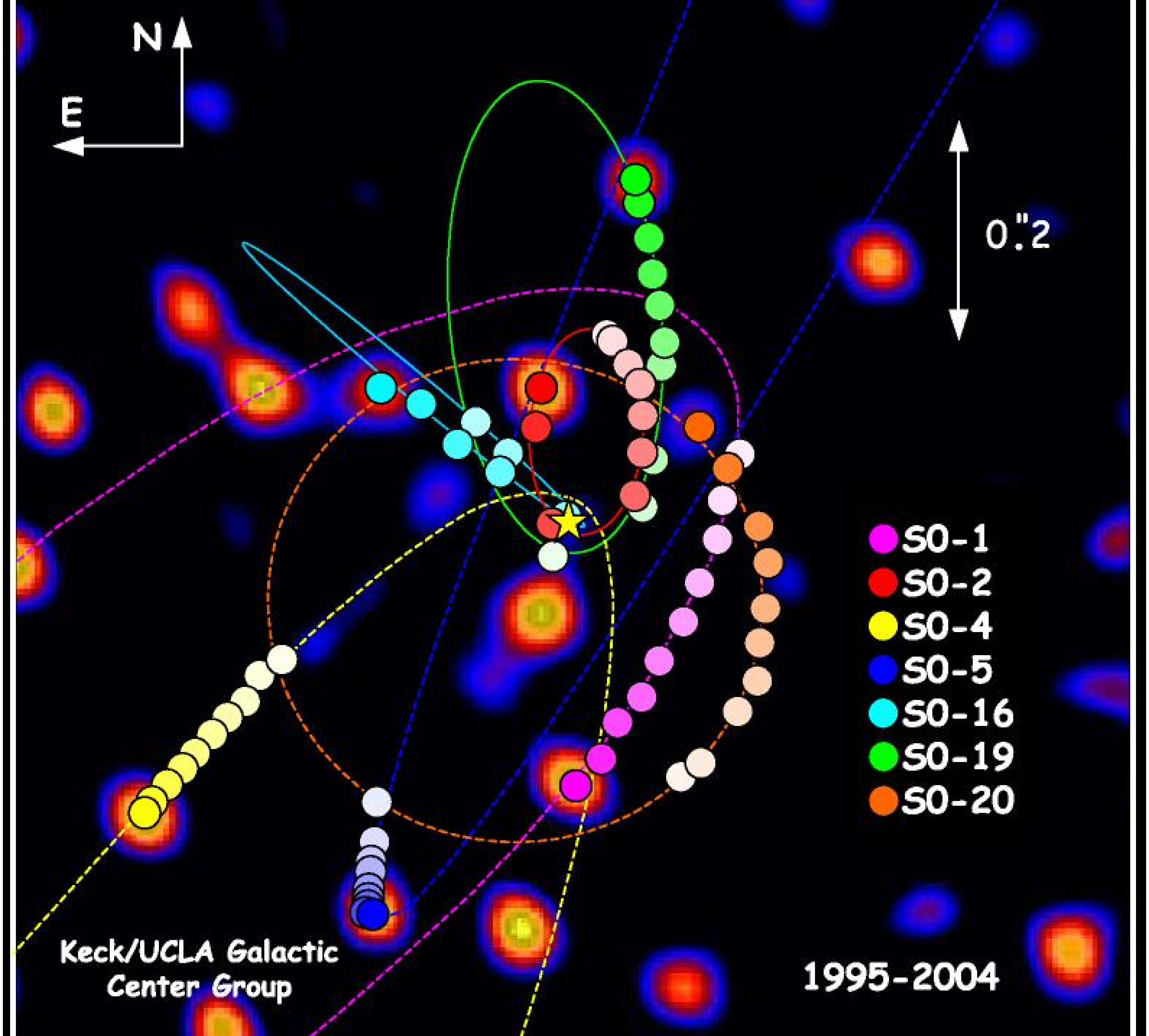
2003-2004 Several flares – quasi periodicity of 17 mins – spin ?

INFRA RED(NACO 2002)

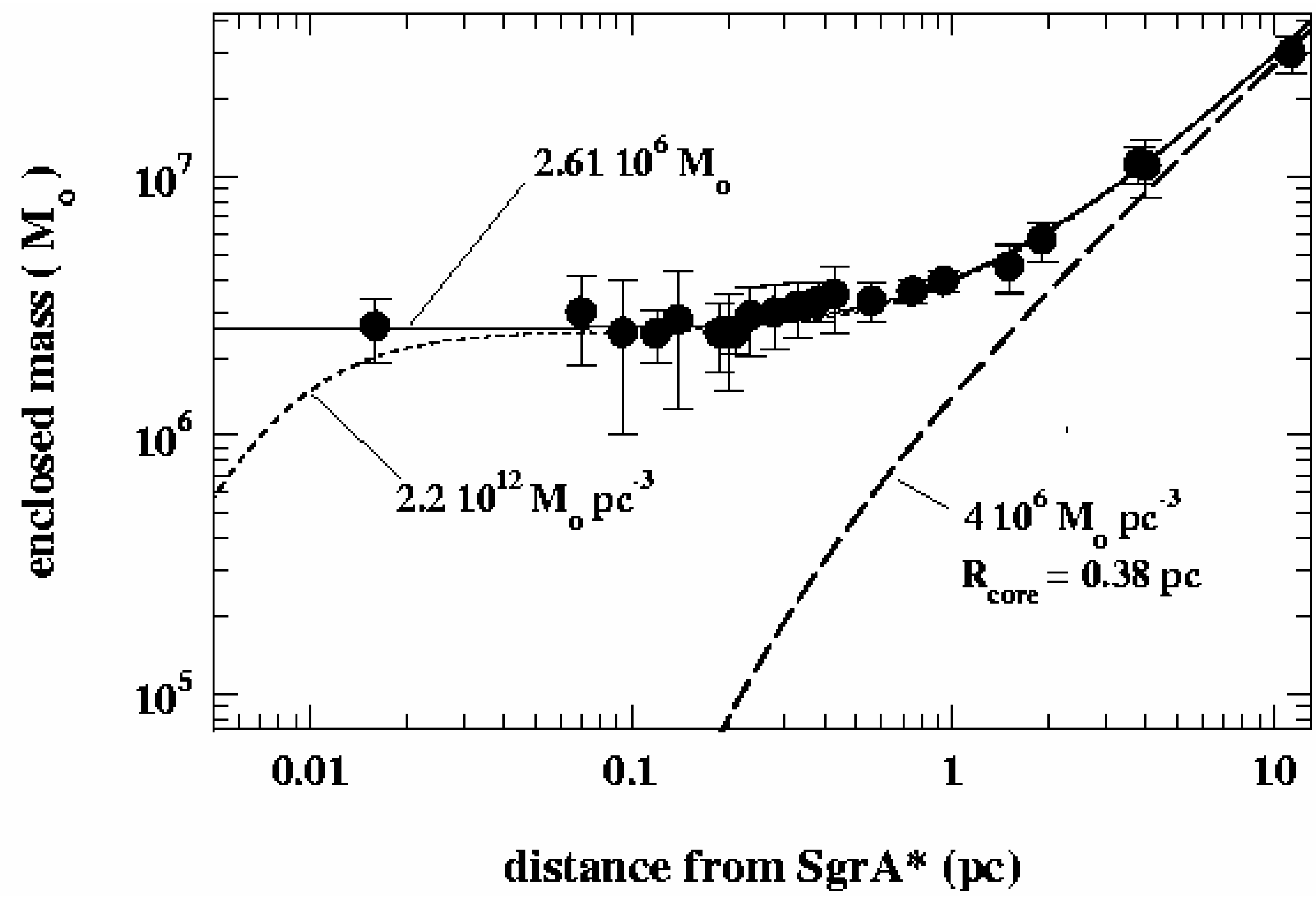


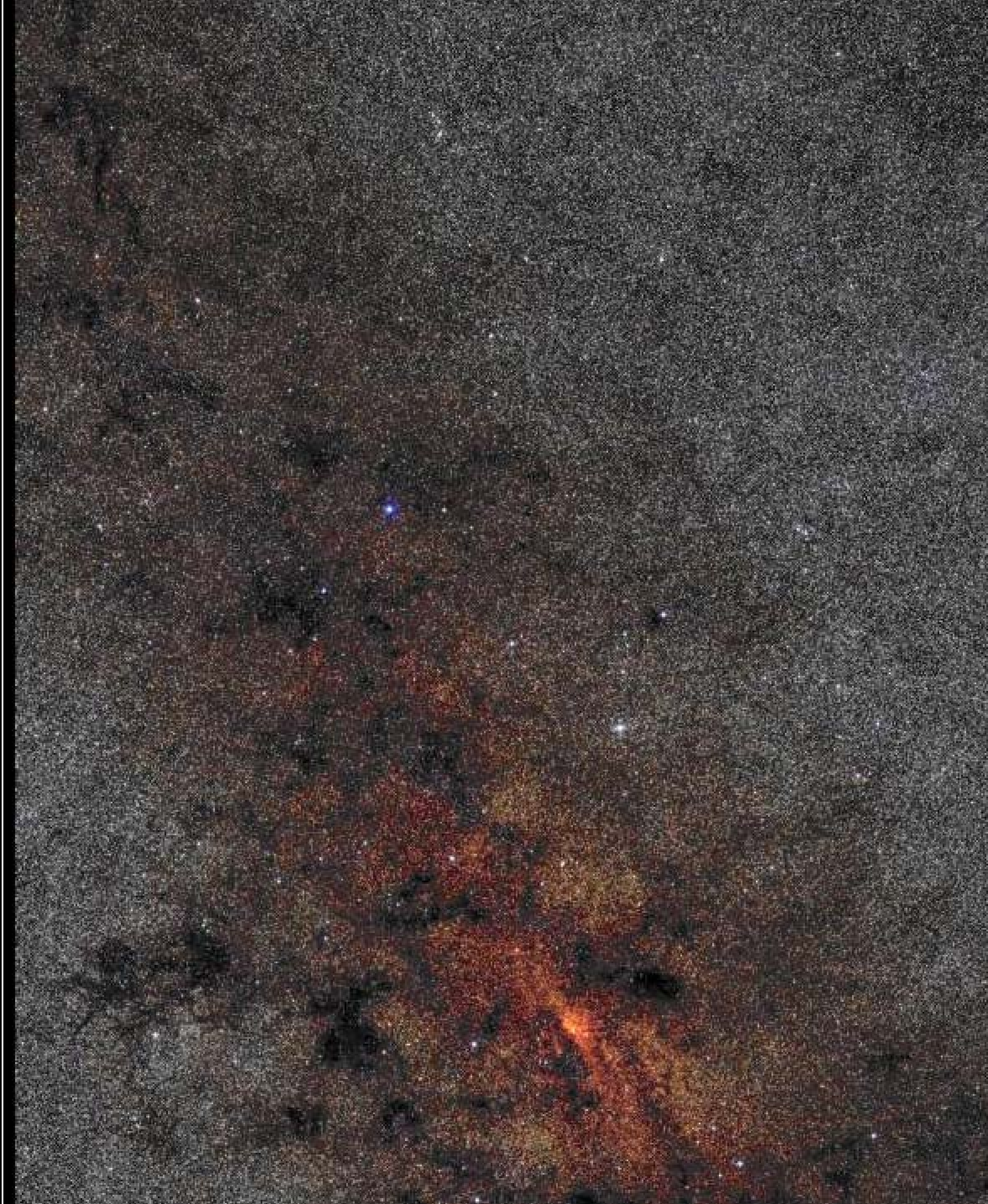
The Centre of the Milky Way
(VLT YEPUN + NACO)

ESO PR Photo 23a/02 (9 October 2002)


N
E
0."2
S0-1
S0-2
S0-4
S0-5
S0-16
S0-19
S0-20
Keck/UCLA Galactic
Center Group
1995-2004

Inferred Mass of BH





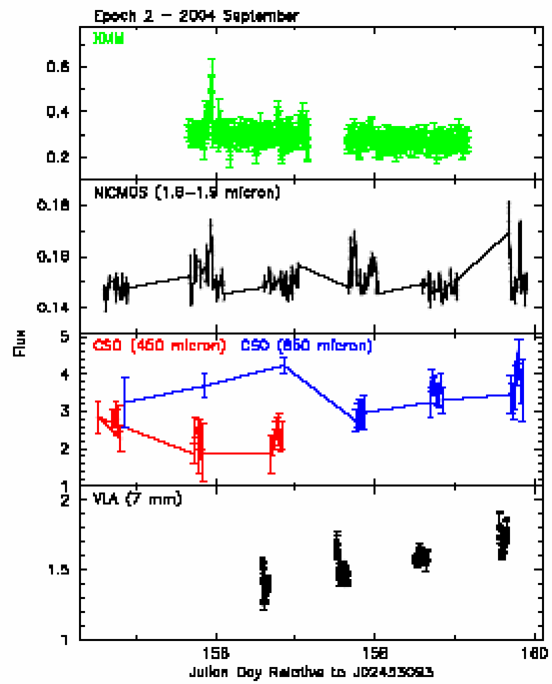
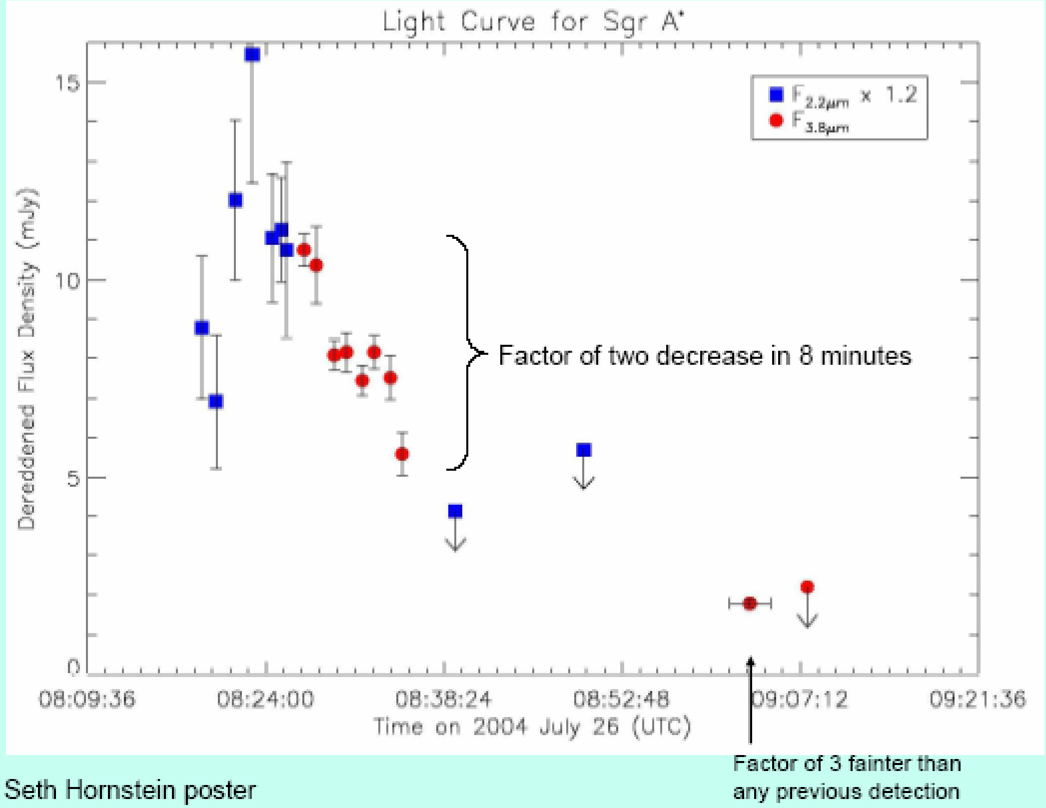


Fig. 8.— The simultaneous X-ray, near-IR, submillimeter, and radio emission from Sgr A* based on the second epoch of observations using XMM, HST, CSO, and VLA. The 8h periodic dips detected in the X-ray light curve are due to the eclipses of the transient, as described in Porquet et al. 2005).

2004 Keck result using laser guide star adaptive optics:



e Seth Hornstein poster

Cosmic Ray anisotropy (10**18 ev)

- AGASA and SUGAR ground arrays both found a source near GC
- Possible source near Sgr. A East ?

AGASA Array

- AGASA
  - 111 scintillation counters of 2.2m^2
  - 100 km^2 area, about 1 km spacing
  - 900 m above sea level
  - Trigger requirement: coincidence of 5 adjacent detectors
  - Data from 1984 – 1995 (With 12 km^2 for first 5 years)

Astroparticle Physics 10 (1999) 303

  - 3 degree angular resolution

Abstract

Quick Search: within

Astroparticle Physics
Volume 10, Issue 4, May 1999, Pages 303-311

Anisotropy in the arrival directions of cosmic rays with energies above 10^{17} eV (1999)

Akeno 20 km^2 array and the Akeno Giant Air Shower Array (AGASA)

~ 114 000 showers observed over 11 years. A strong anisotropy of ~ 4% around 10^{18} eV, corresponding to a chance probability of 0.2% .

This anisotropy is interpreted as an excess of showers near the directions of the Galactic Center and the Cygnus region.

Corresponding author.
Present address: Institute for Cosmic Ray Research, Univ. of Tokyo, Midori-cho 3-2-1, Tanashi, Tokyo 188-8502, Japan

Evidence for EHE CR Anisotropy

- **AGASA – Japanese, giant air-shower array – finds anisotropy (~25 % over-abundance) at the 4 σ level towards the GC over a 20 degree diameter circle for 17.9 < log[E/eV] < 18.3**

  Re-analysis of SUGAR data (1968-1979) also uncovers point source near GC (4000 events within *a priori* restricted energy range) – Bellido et al. 2001.

- **New AGASA data strengthens case for anisotropy: get 4.5 σ result for 18.0 < log[E/eV] < 18.4**

- **AGASA also sees enhancement towards Cygnus (3 σ effect) and a deficit towards the Galactic anti-center (3.7 σ effect)**

- **Fly's Eye: Galactic Plane enhancement at 3.2 σ (Bird et al. 1999) for**

  17.3 < log[E/eV] < 18.5

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What's the Source?

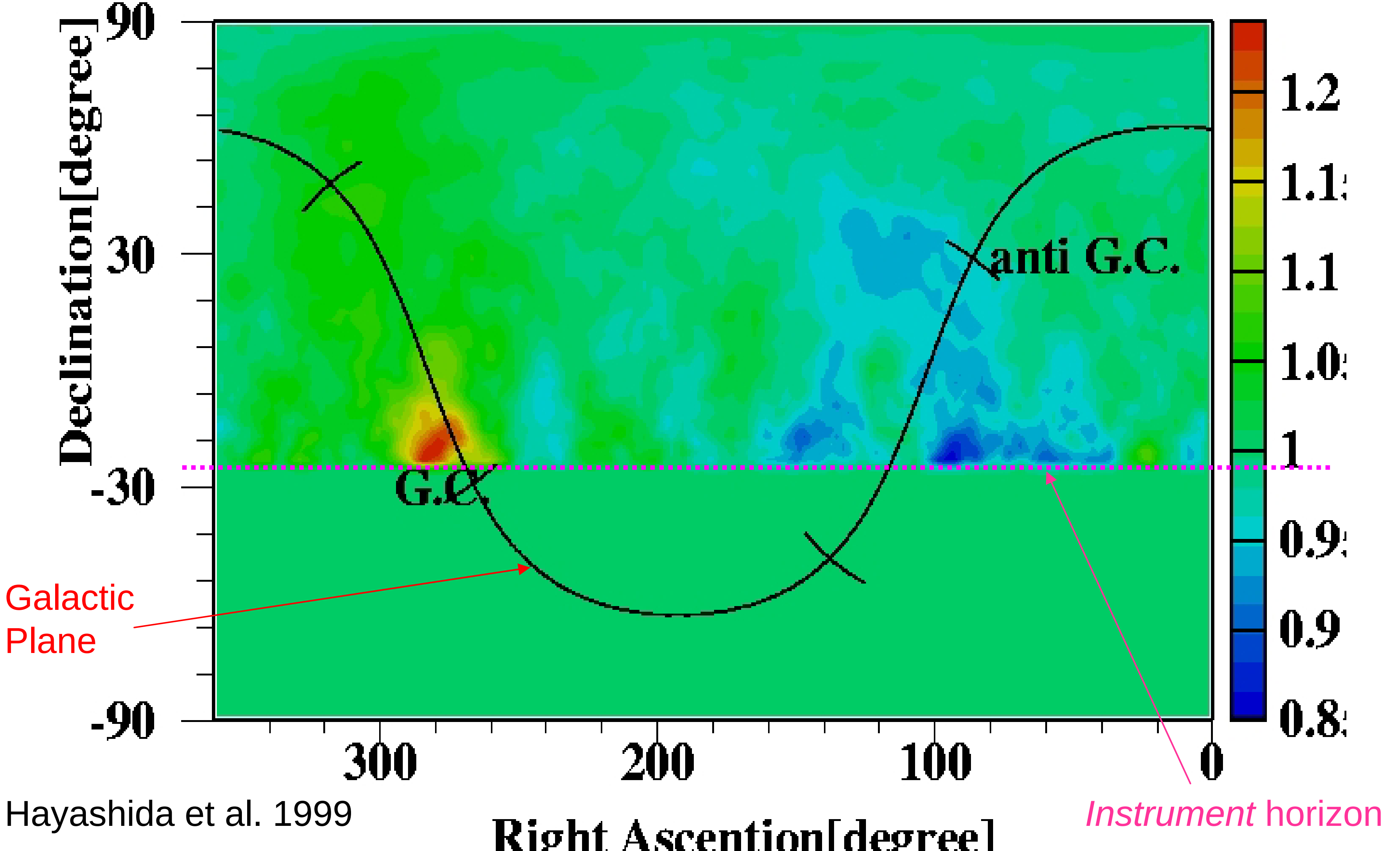
- A natural explanation of this phenomenon is that it is due to **neutrons** generated at the GC: the Lorentz-boosted decay length of the neutron becomes equal to the distance to the GC at precisely the energy at which the anisotropy turns on – i.e., a neutron at 10^{18} eV experiences a quarter of an hour in its propagation from the GC

8 + - 0.5 kpc

•- a conventional astrophysical explanation for the production of these putative EHE neutrons: that they are produced in **proton-proton** collisions at the supernova remnant **Sgr A East** located near the GC

•

AGASA CR Sky

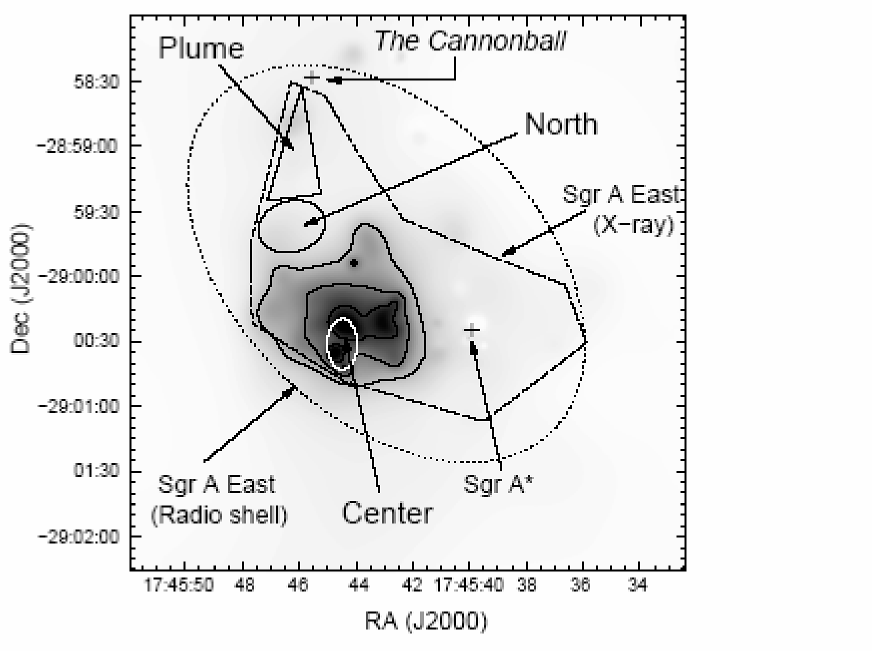


Hayashida et al. 1999

Some Other Inhabitants of GC

High vel. Neutron Star

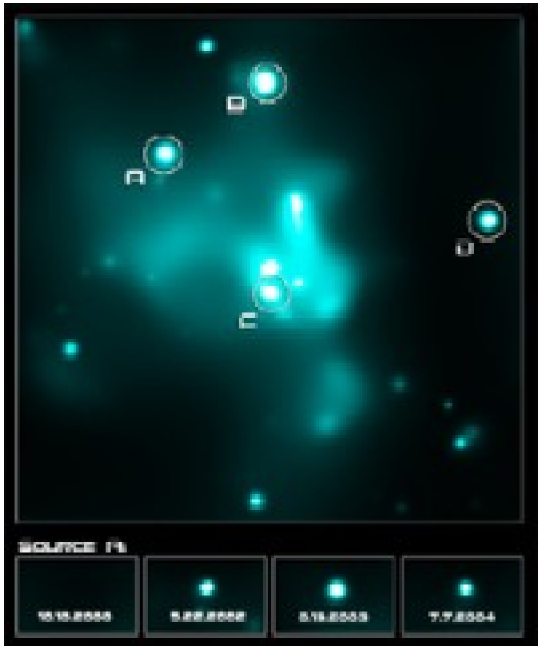
- 2 ‘ separation between SNR centre and source - Hard X-ray spectra - Possibly same origin ?



More strange objects !

.2005 – Chandra found 4 x-ray binaries very near – GC(< 3 LY) – Highly variable

- **Expect ~10000 stellar BHs near GC region**
- **Dynamical friction – migration towards gal.centre = eventually eaten up by SMBH**
- **Stellar Graveyard !**



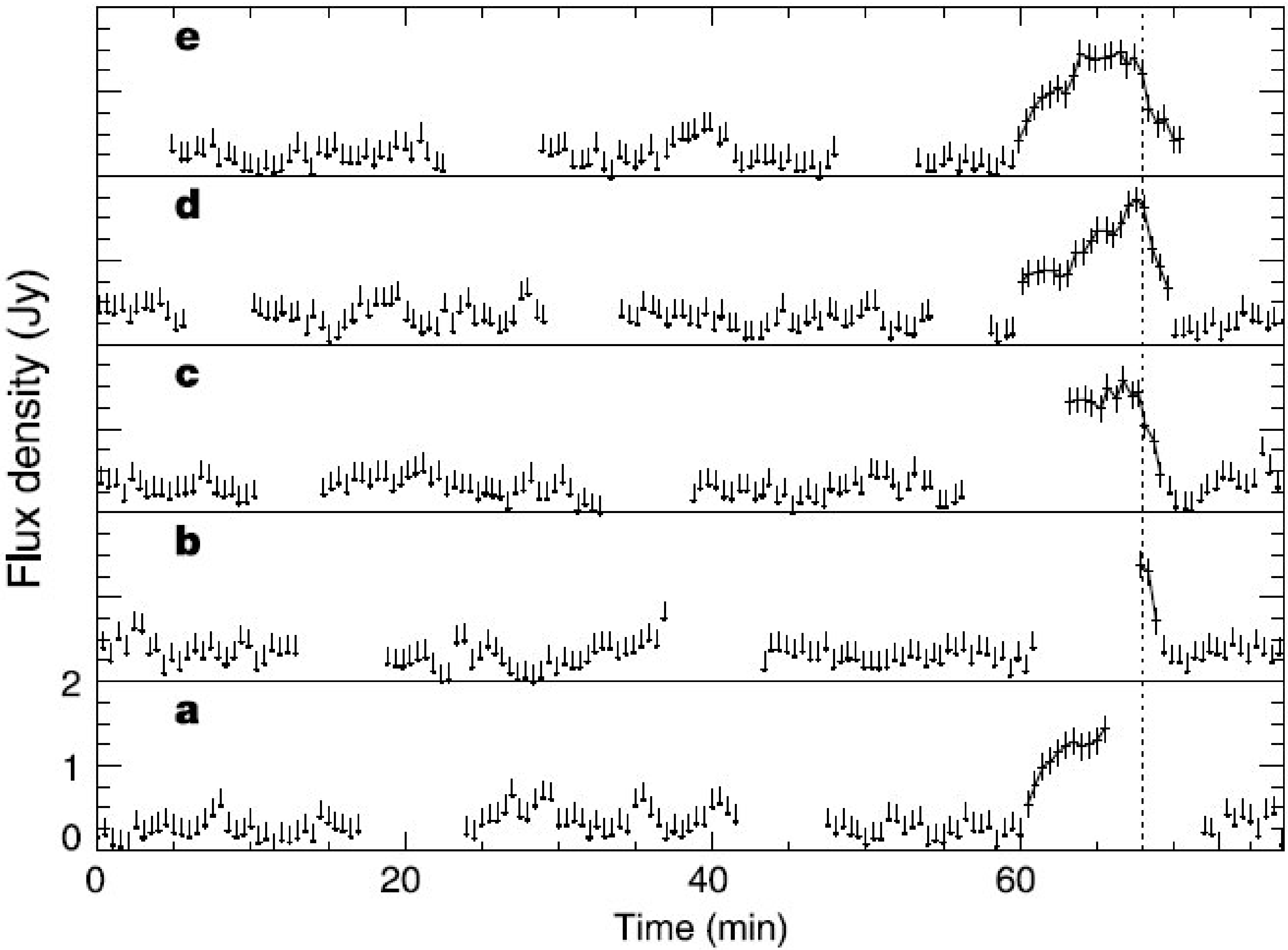
Radio Blasts ! New type of source

March 2005 – Hyman et al larger region of the sky- 5 strong bursts (~10 min duration) – separated by 77mins- same region of the sky near Gal centre GCRT 1745-3009

Source size ~ small

Near ? Far? Known type of object?

Pulsar in dying stages – Burper?



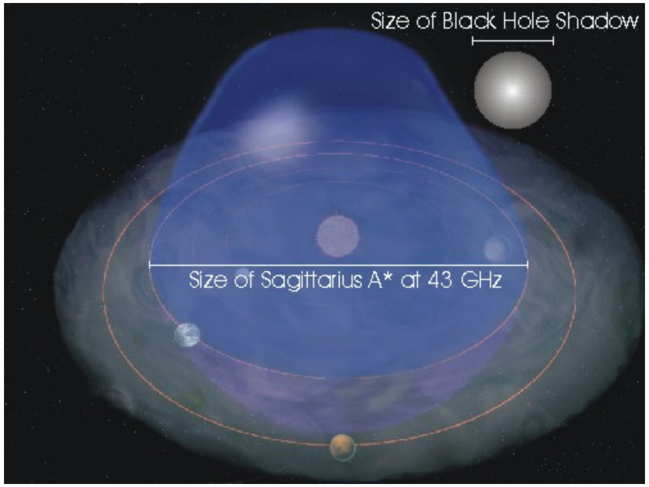
e
d
c
b
a
Flux density (Jy)
2
1
0
0
20
40
60
Time (min)

Must Sgr A* be a SMBH?

Object	Density (M_{sun}/pc^3)	Method	Mass & Radius
M 87	2×10^6	HST:	$3\times10^9\ M_{sun}$ in 7 pc
NGC 4258	7×10^9	VLBA : H_2O	$3\times10^7\ M_{sun}$ in 0.1 pc
Sgr A*	2×10^{17}	S2's orbit	$4\times10^6\ M_{sun}$ in 45 AU
Sgr A*	2×10^{19}	excursions	$4\times10^6\ M_{sun}$ in 4 AU
Sgr A*	7×10^{21}	proper motion	$4\times10^5\ M_{sun}$ in 0.5 AU
SMBH	2×10^{25}	R_{sch}	$4\times10^6\ M_{sun}$ in 0.08 AU

(10μas @ 8kpc)

VLBI (eg, SMA-ALMA-LMT-CARMA…) @ 1 mm -> 20 uas



Size of Black Hole Shadow
Size of Sagittarius A* at 43 GHz

Black holes

Sparks of interest

Ramesh Narayan

Why is the black hole at the centre of our Galaxy so dim, when those in other galaxies can outshine the stars around them? Newly discovered bursts of infrared radiation may give the first clues to what is going on.

At the centre of the Milky Way is a supermassive black hole called Sagittarius A* (Sgr A*)[1,2]. As supermassive black holes go, Sgr A* is a relatively small one: it's four million times more massive than the Sun, but black holes up to 1,000 times more massive are known to exist in other galaxies. What makes Sgr A* special is that it is by far the closest supermassive black hole to Earth, making it a prime target for study. And, of course, it is our black hole, at the centre of our own Galaxy. Another, curious, feature is that Sgr A* is one of the dimmest black holes known.

Sgr A* has been studied extensively at long wavelengths, through the detection of radio- and millimetre-wavelength radiation from it; only recently has that information been complemented by images at shorter wavelengths, taken by the space-borne Chandra X-ray Observatory[3]. On page 934 of this issue, Genzel and colleagues[4] add more detail, with their detection of Sgr A* at infrared wavelengths, using the Very Large Telescope in Chile's Atacama Desert. Genzel *et al.*, and another group led by Ghez[5], find that the brightness of Sgr A* at infrared wavelengths is highly variable, and flares frequently. These observations, reflecting similar patterns seen earlier in X-rays, open

While it is the closest SMBH and good for studies

(1) Sgr A* is a relatively small one

(2) one of the dimmest black holes known. SMBH in distant galaxies are observed as quasars, accrete (absorb) a lot of gas from their surroundings and~ 10%, of the mass energy of that gas converted to radiation-luminosities ~ nearly equal to the maximum allowed(Eddington limit)

Sgr A*, in contrast, is extremely dim, radiating at only a billionth of the Eddington limit for its mass.

Why is Sgr A* so dim?

(1)It has less gas to accrete, compared with the bright black holes in quasars — but this is only ~ 10,000 times less

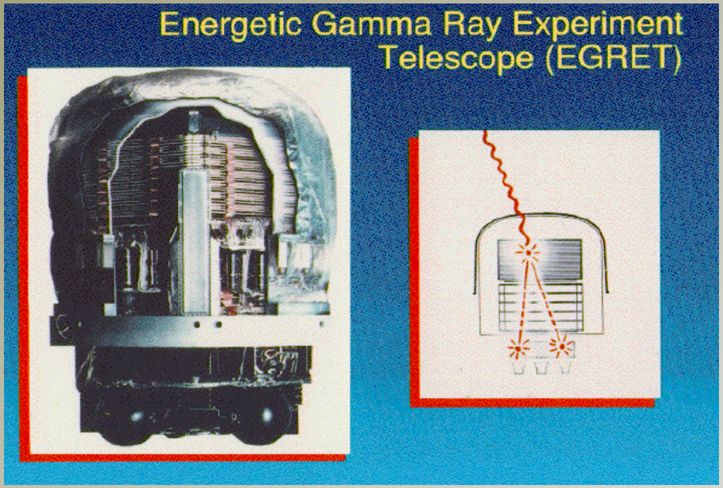
(2) the gas flow in Sgr A* s radiatively inefficient: only a very small fraction of its mass energy is converted to radiation.

(3) Therefore, only a small fraction of the available gas actually accretes onto the black hole, the rest being ejected from the system.

This still leaves the fundamental question : Something is clearly different about the physics in bright black holes and in dim ones.

Satellite Based Gamma Ray Astronomy

Compton Gamma Ray Observatory
(1991-2000)



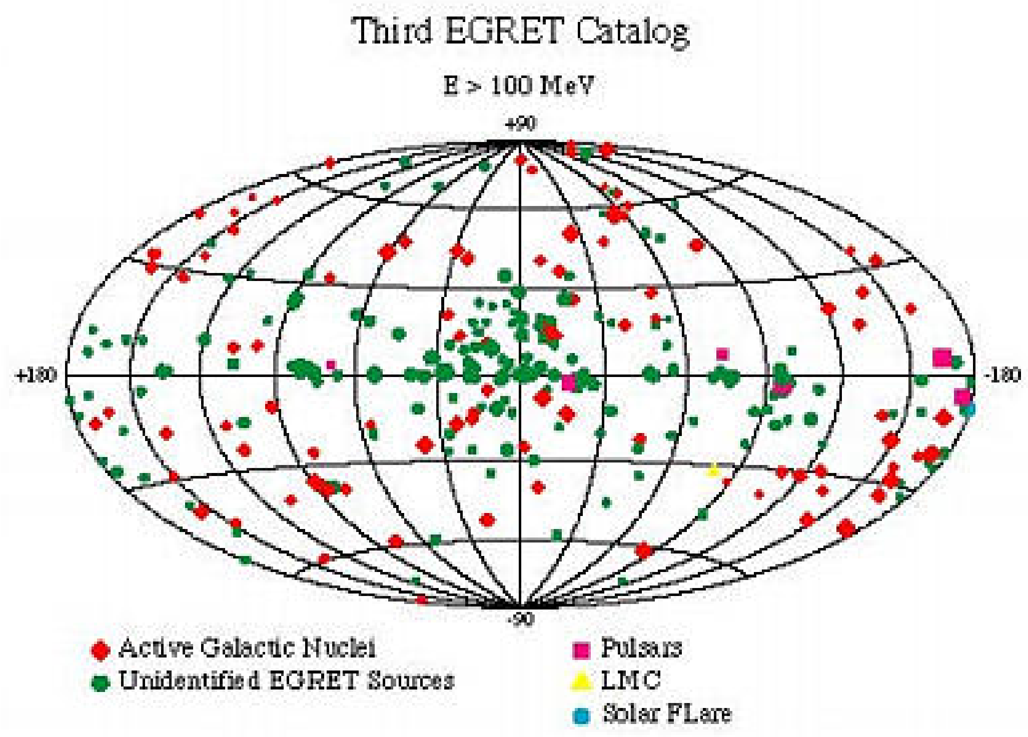
Energy range :
20 MeV – 30 GeV

GLAST

Launch expected in 2007

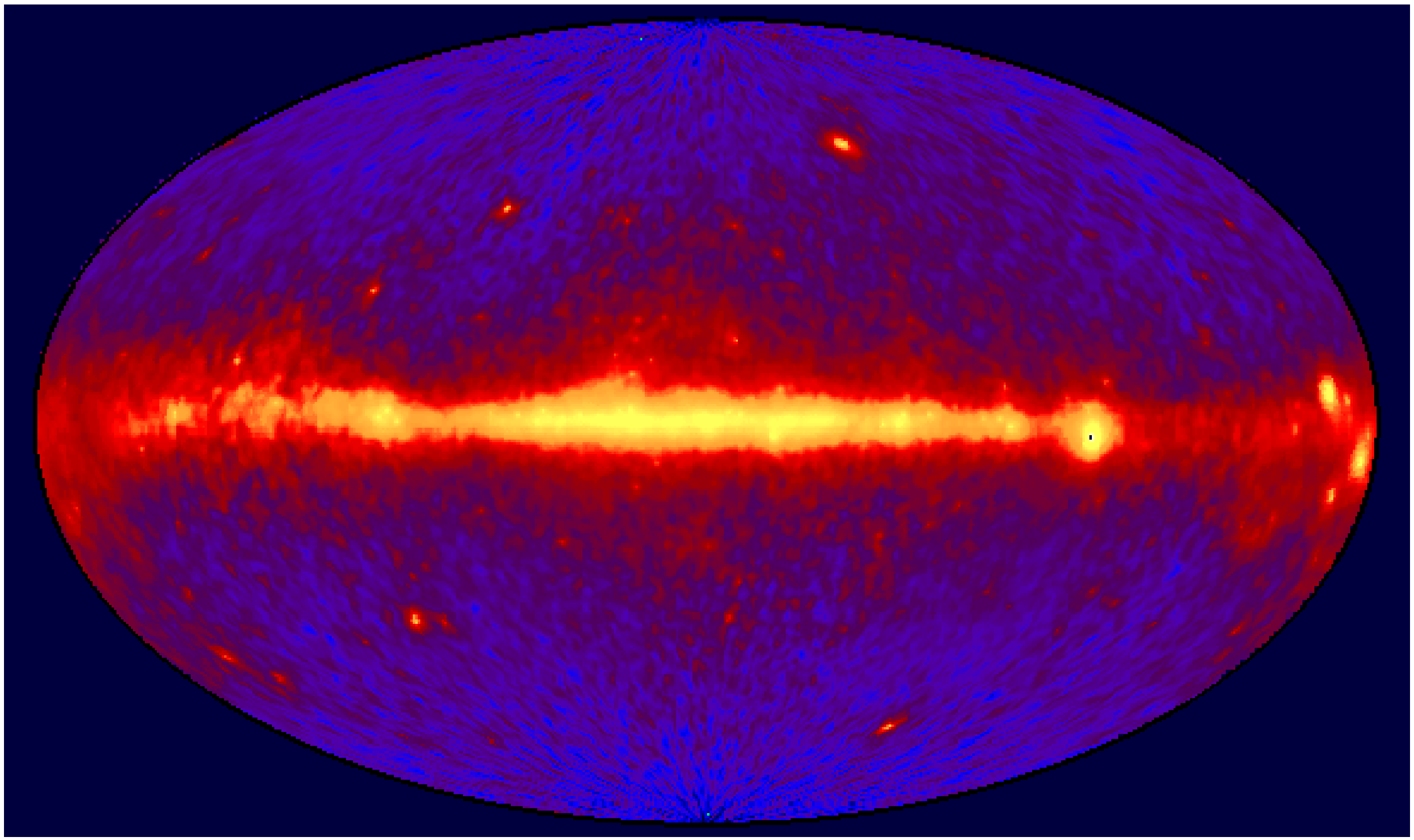
Energy range : 10 MeV – 100 GeV

+++



Third EGRET Catalog
E > 100 MeV
+90
+180
-180
-90
Active Galactic Nuclei
Unidentified EGRET Sources
Pulsars
LMC
Solar FLare

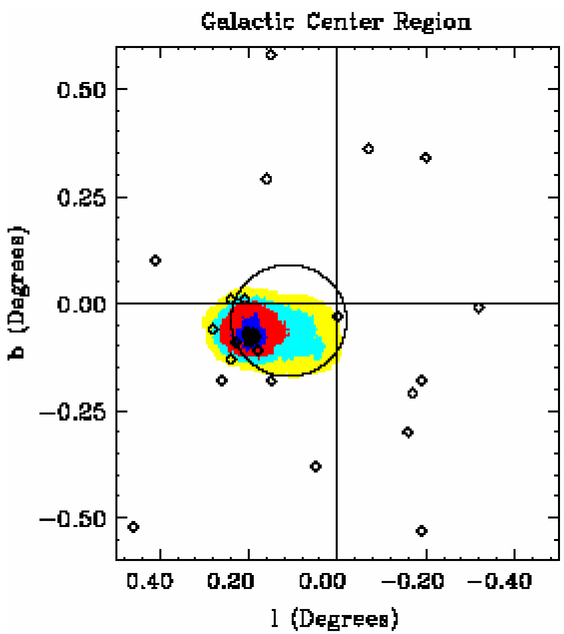
GAMMA RAY (EGRET)



Gamma rays are expected from the Galactic Center

Why?

- Because there is a supermassive back hole.
- Because there are a number of compact objects.
- Because the annihilation signal from dark matter should show a spike.
- Because we see a lot of non-thermal activity in the inner 100 pc.



Galactic Center Region
0.50
0.25
0.00
−0.25
−0.50
b (Degrees)
0.40
0.20
0.00
−0.20
−0.40
l (Degrees)

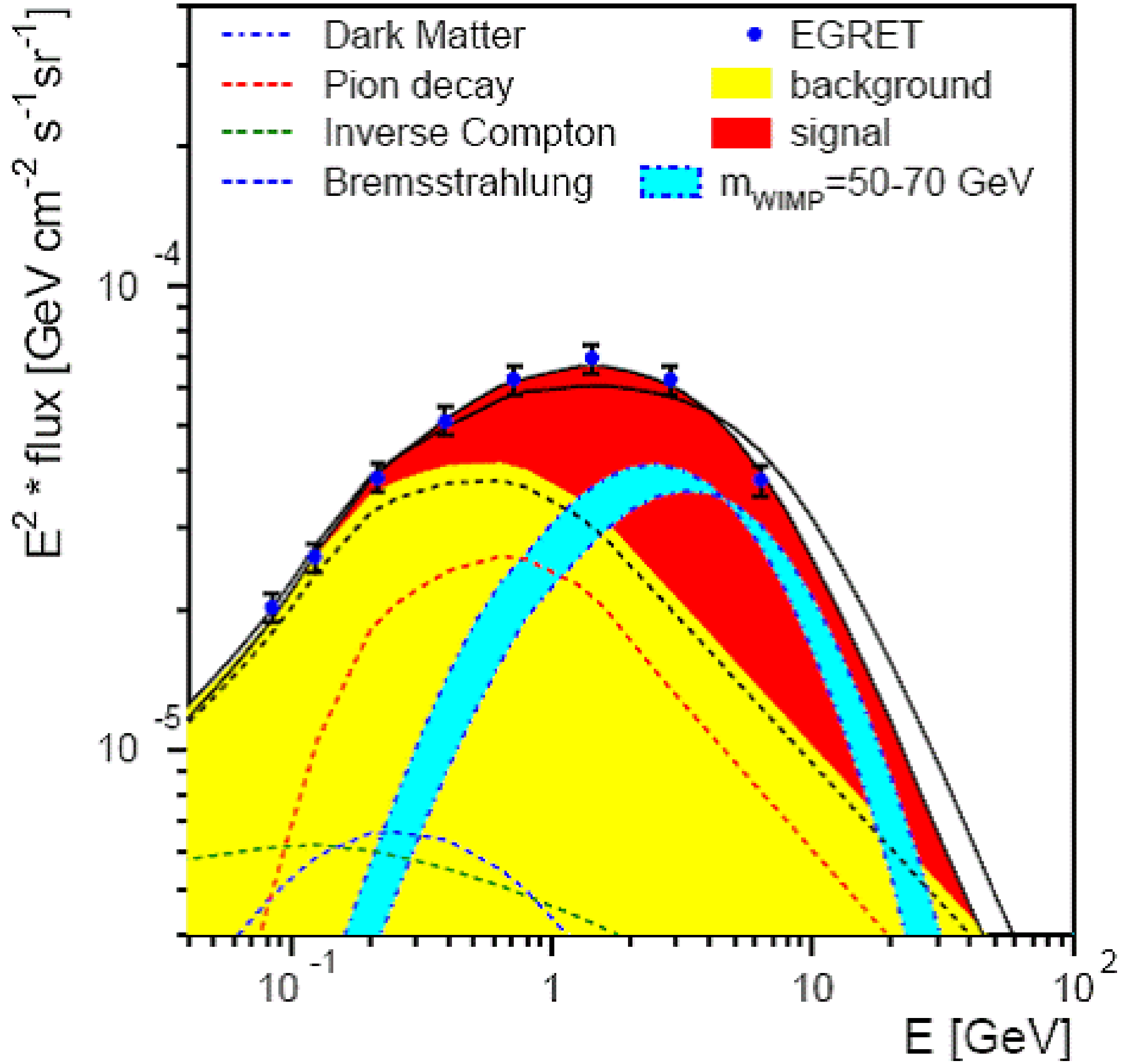
Low Energy Gamma Rays

(1) EGRET ~ strong unid source 3EG 1746-2851; marginally consistent with GC . 3 different analyses source may be offset from Sgr A* - hard spectrum may cut off > few GeV

(But limited angular resolution – GLAST)

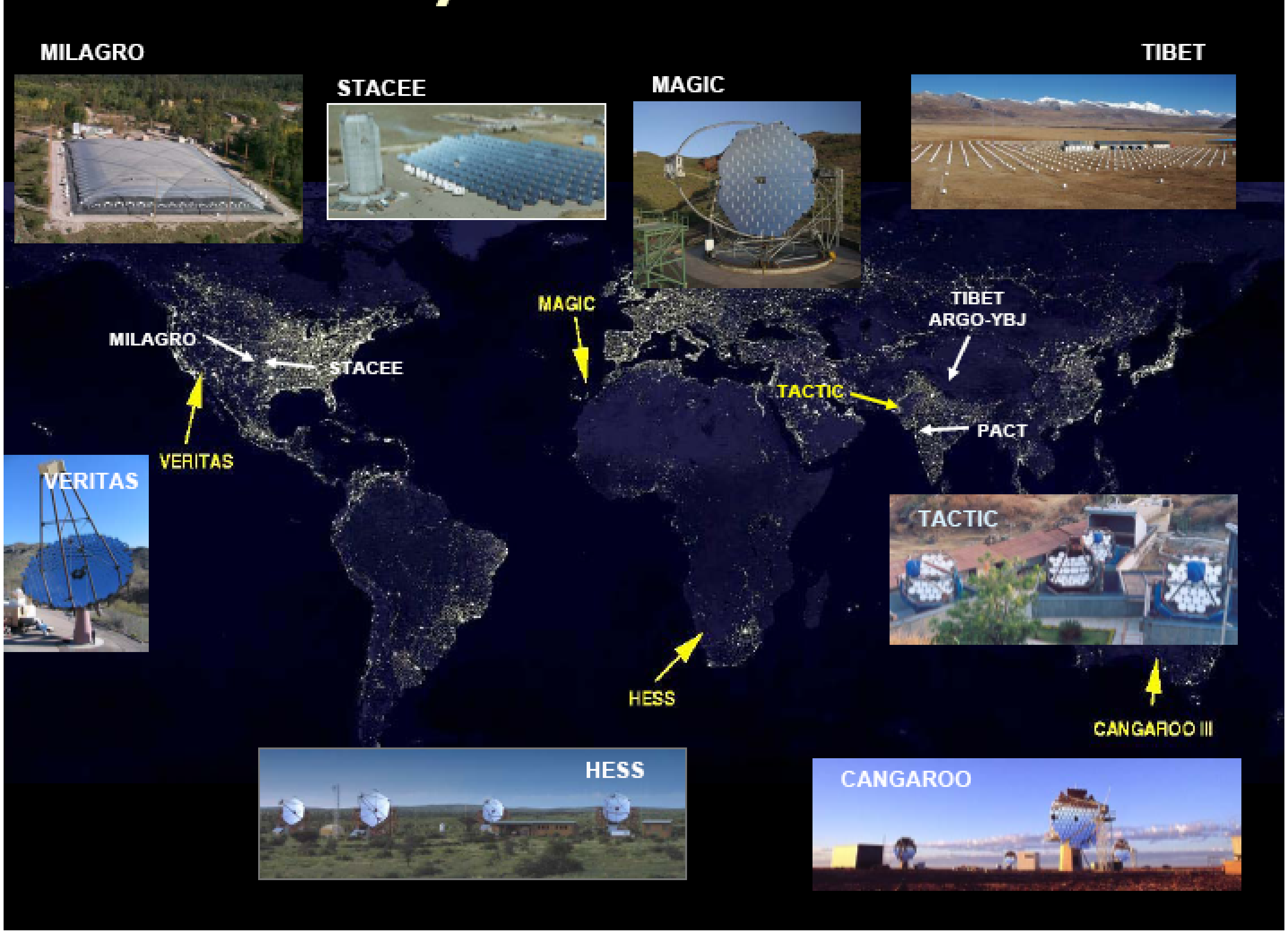
(1) INTEGRAL (15 kev –10 mev)

time variable emission from within 0.9 ‘ of Sgr A*



Dark Matter
Pion decay
Inverse Compton
Bremsstrahlung
EGRET
background
signal
m_{WIMP}=50-70 GeV
E^2 * flux [GeV cm^{-2} s^{-1}sr^{-1}]
10^{-4}
10^{-5}
10^{-1}
1
10
10^{2}
E [GeV]

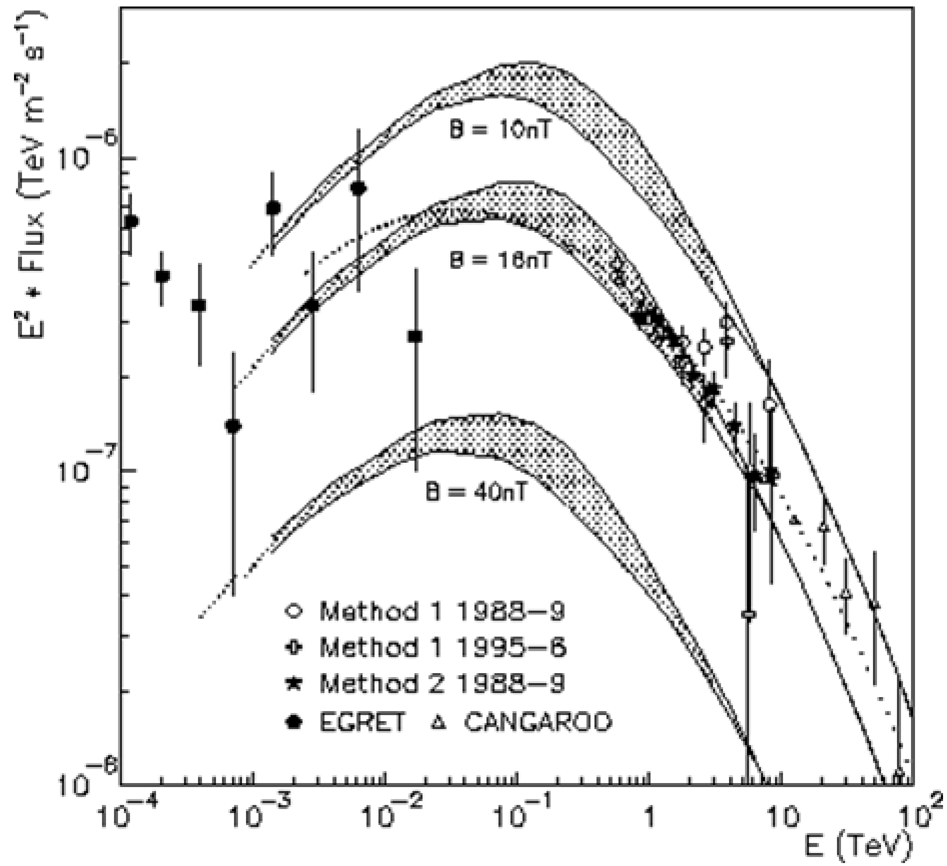
VHE Astronomy World



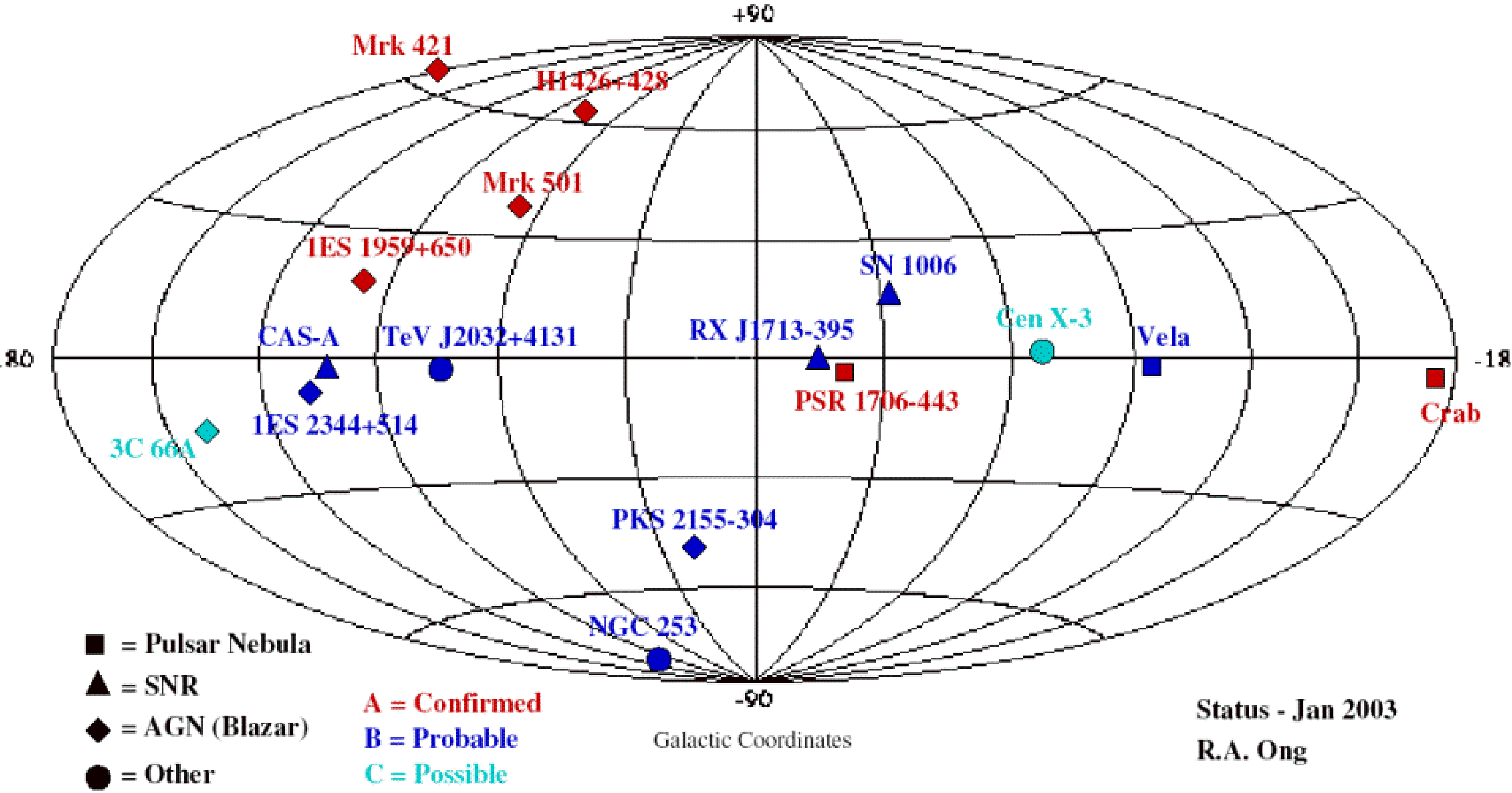
University Lowbrow Astronomers

Ann Arbor, Michigan

Energy Spectrum from Crab Nebula from many experiments – Crab is a standard candle inVHE gamma rays

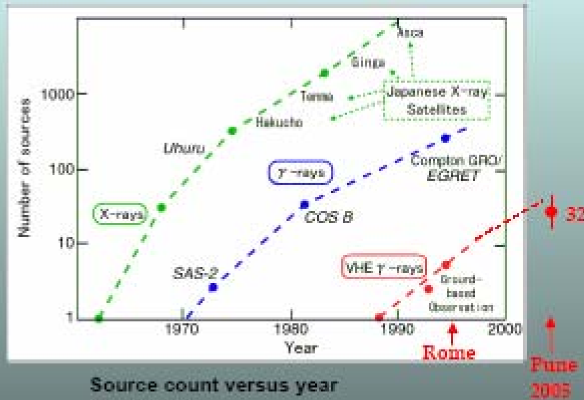


Theoretical curves for different nebular magnetic field. VHE gamma ray astronomy ‘ fixes’ the magnetic field !



+90
Mrk 421
H1426+428
Mrk 501
1ES 1959+650
SN 1006
CAS-A
TeV J2032+4131
RX J1713-395
Cen X-3
Vela
PSR 1706-443
Crab
1ES 2344+514
3C 66A
PKS 2155-304
NGC 253
-90
■ = Pulsar Nebula
▲ = SNR
◆ = AGN (Blazar)
● = Other
A = Confirmed
B = Probable
C = Possible
Galactic Coordinates
Status - Jan 2003
R.A. Ong

"Kifune Plot"



Source count versus year
[T. Kifune]

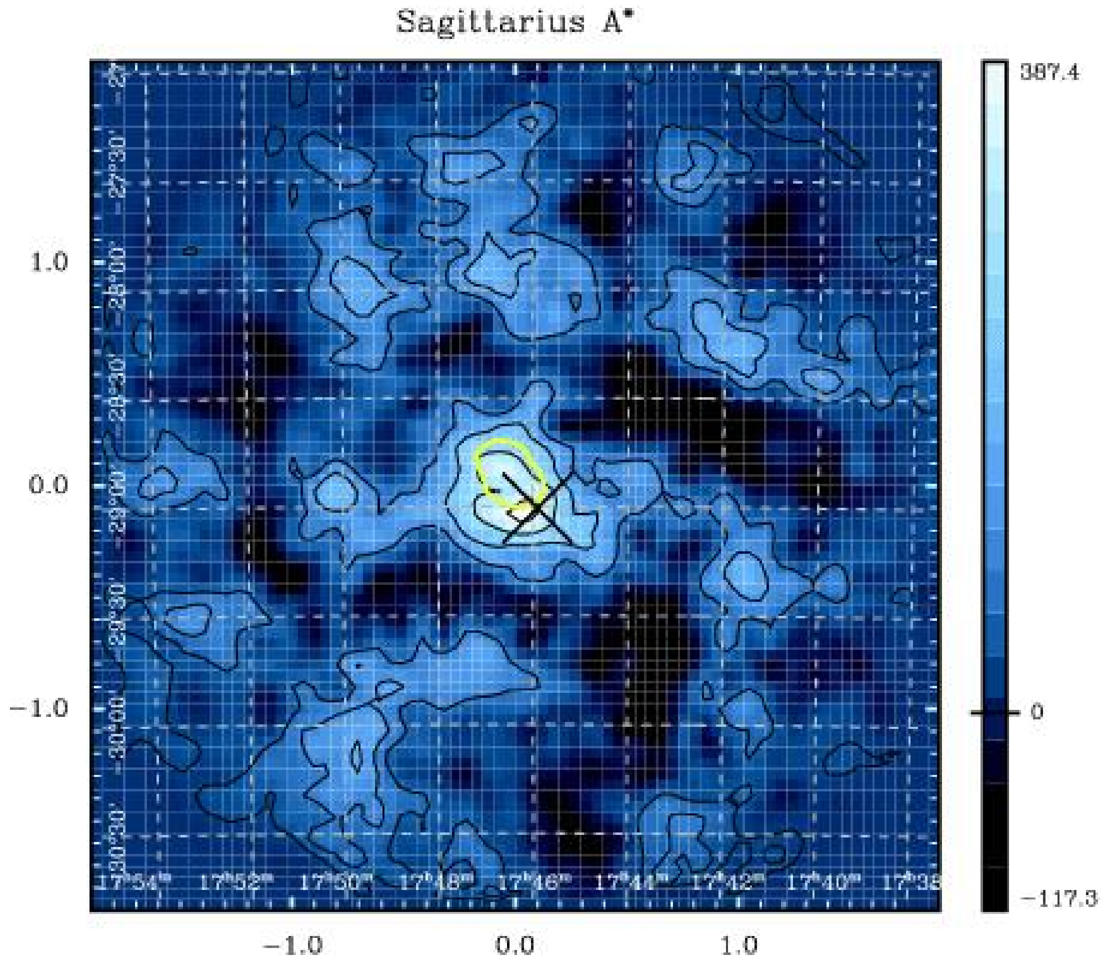
Source Counts

Source Type*	2003	2005
Pulsar Wind Nebula (e.g. Crab, MSH 15-52 ...)	1	6
Supernova Remnants (e.g. Cas-A, RXJ 1713 ...)	2	6
Binary Pulsar (B1259-63)	0	1
Micro-quasar (LS 5039)	0	1
Diffuse (Cygnus region)	0	1
AGN (e.g. Mkn 421, PKS 2155 ...)	7	11
Unidentified	2	6
TOTAL	**12**	**32**

* Includes likely associations of HESS unid sources.

→ Explosion in the number of VHE sources.

Gal Centre (Whipple (1994-2004)~ 26 hours ~ 4 sigma 20 % crab flux; no variation (3 TeV, 0.1-0.2 ang res)



bmb+f - Förderschwerpunkt

Astroteilchenphysik

Großgeräte der physikalischen Grundlagenforschung

Entdeckung von

VHE γ-Strahlung

aus dem Binärsystem

PSR B1259-63 / LS 2883

mit H.E.S.S.

Frank Breitling

High Energy Stereoscopic System

Four telescopes,
107 m^2 mirror area each

4 x 960 PMT cameras,
field of view 5°

Observation in moonless
nights, ~1000 h / year

Each night several objects
are tracked and ~300
images recorded per
second

First analysis (almost)
online in the same night
on cluster in Namibia

Final analysis and
calibration in Europe

Sensitivity:
1% Crab in 25 h

The VHE Source in Galactic Center region

2003: ~ 16 h of two telescope data, 9.2 sigma, spectrum
-> Aharonian et al. 2004, A&A Letter

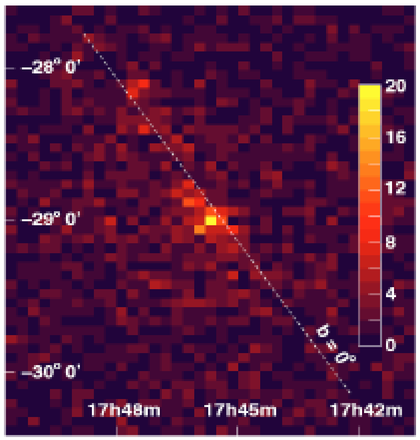
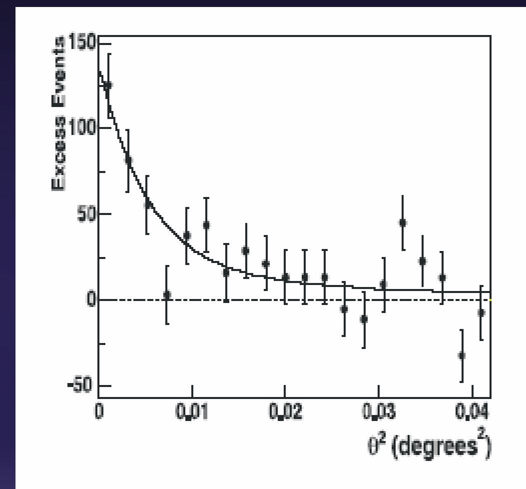


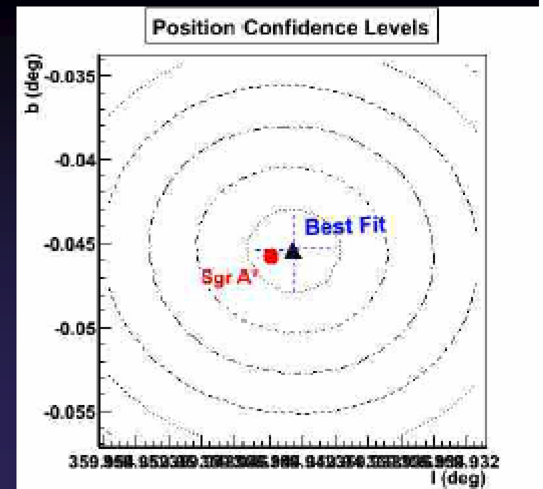
Fig. 1. Angular distribution of γ-ray candidates for a 3° field of view centred on Sgr A*. Both data sets ("June/July" and "July/August") are combined, employing tight cuts to reduce the level of background. The significance of the feature extending along the Galactic Plane is under investigation.



Position and extension (2004)

Assuming point-like source

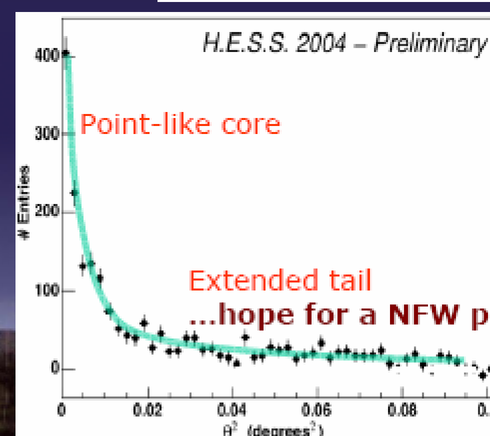
compatible with Sgr A* 5.6''±10''±20''



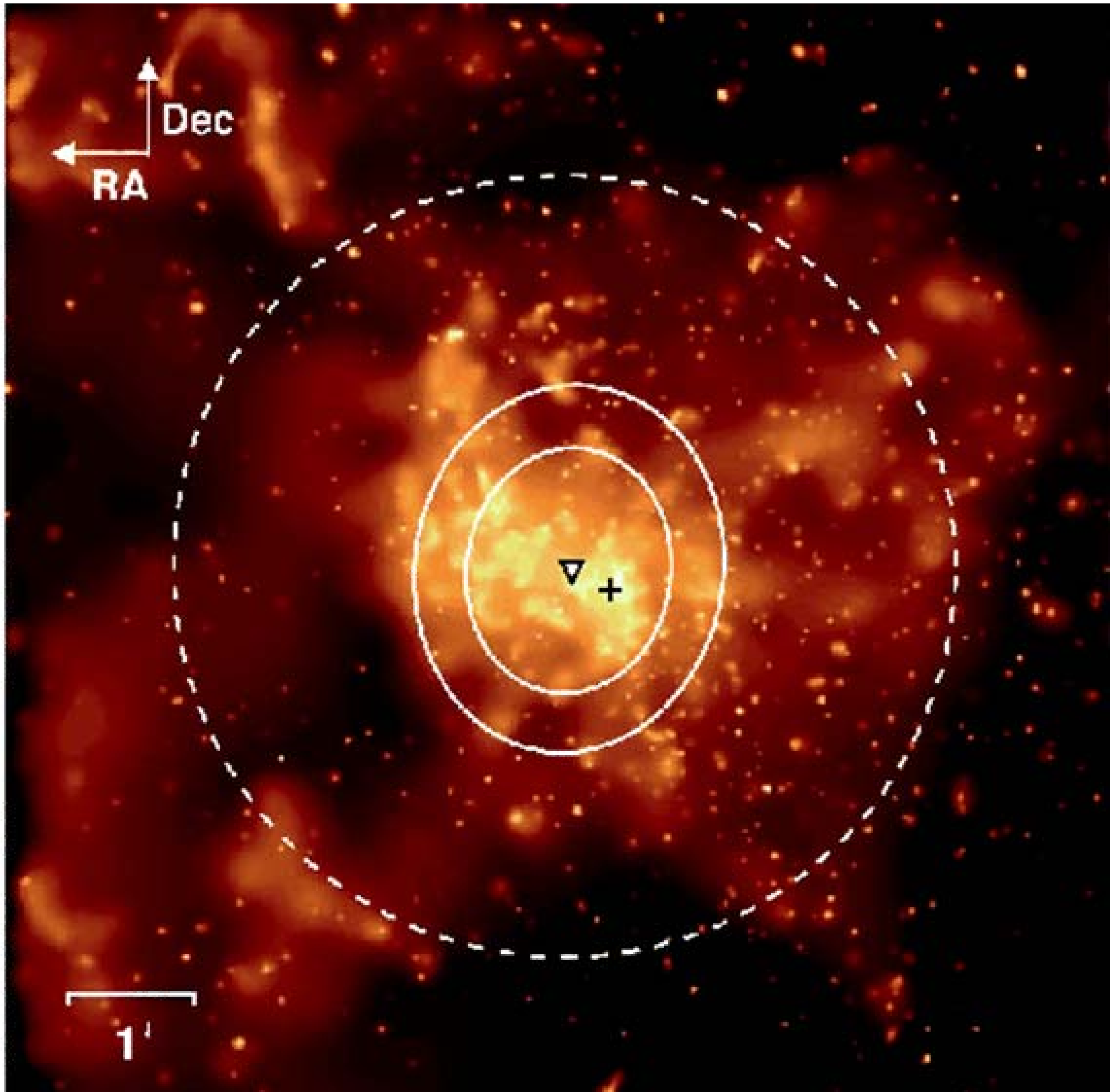
Assuming symmetric gaussian

distance to Sgr A* 3.9''±13''±20''

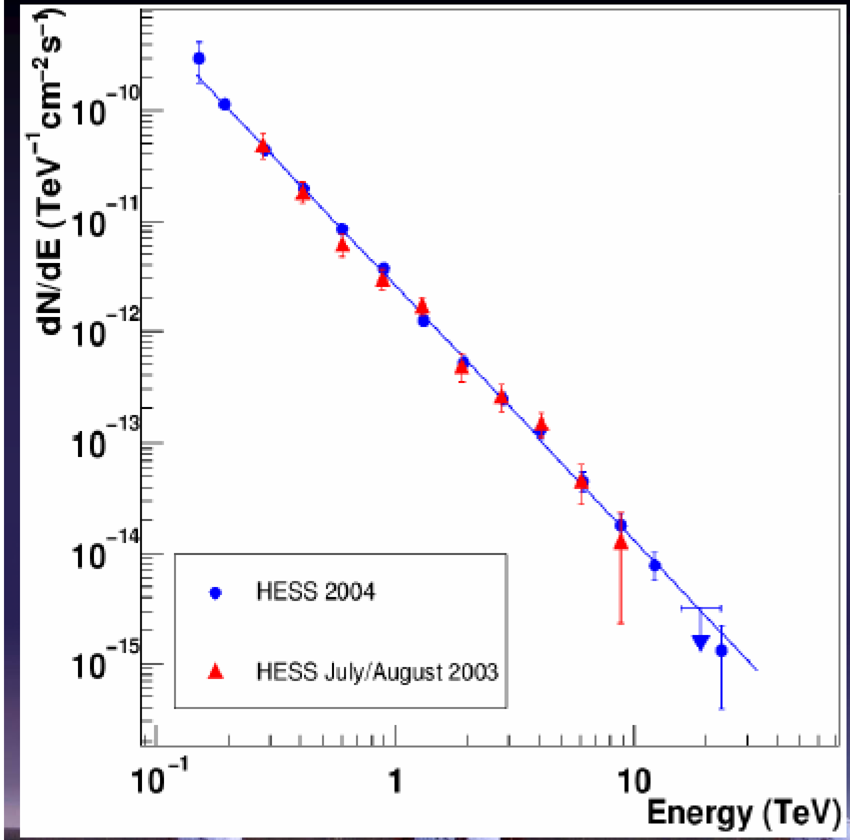
extension: 1.9' ± 0.23'



GC(HESS)2004 >165 GeV (~40 Hrs) **Chandra map(+ Sag A*, tria- Hess centroid)**



Gamma ray spectrum



Power law,

index 2.3

No significant variability

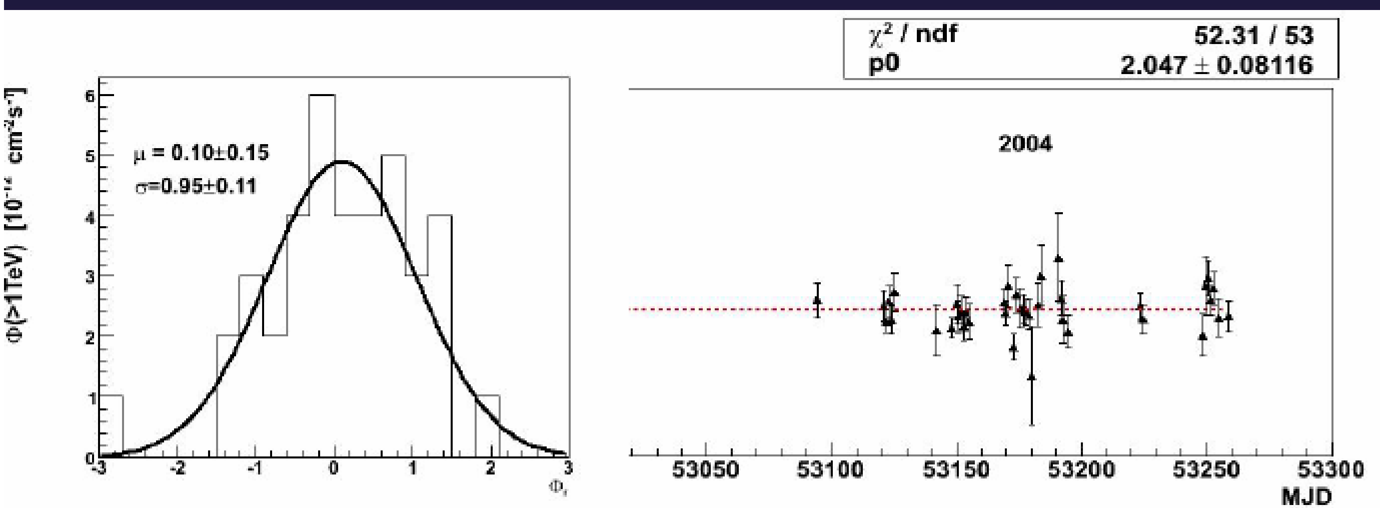
- on year scale
- on month scale
- on day scale
- on hour scale
- on minute scale

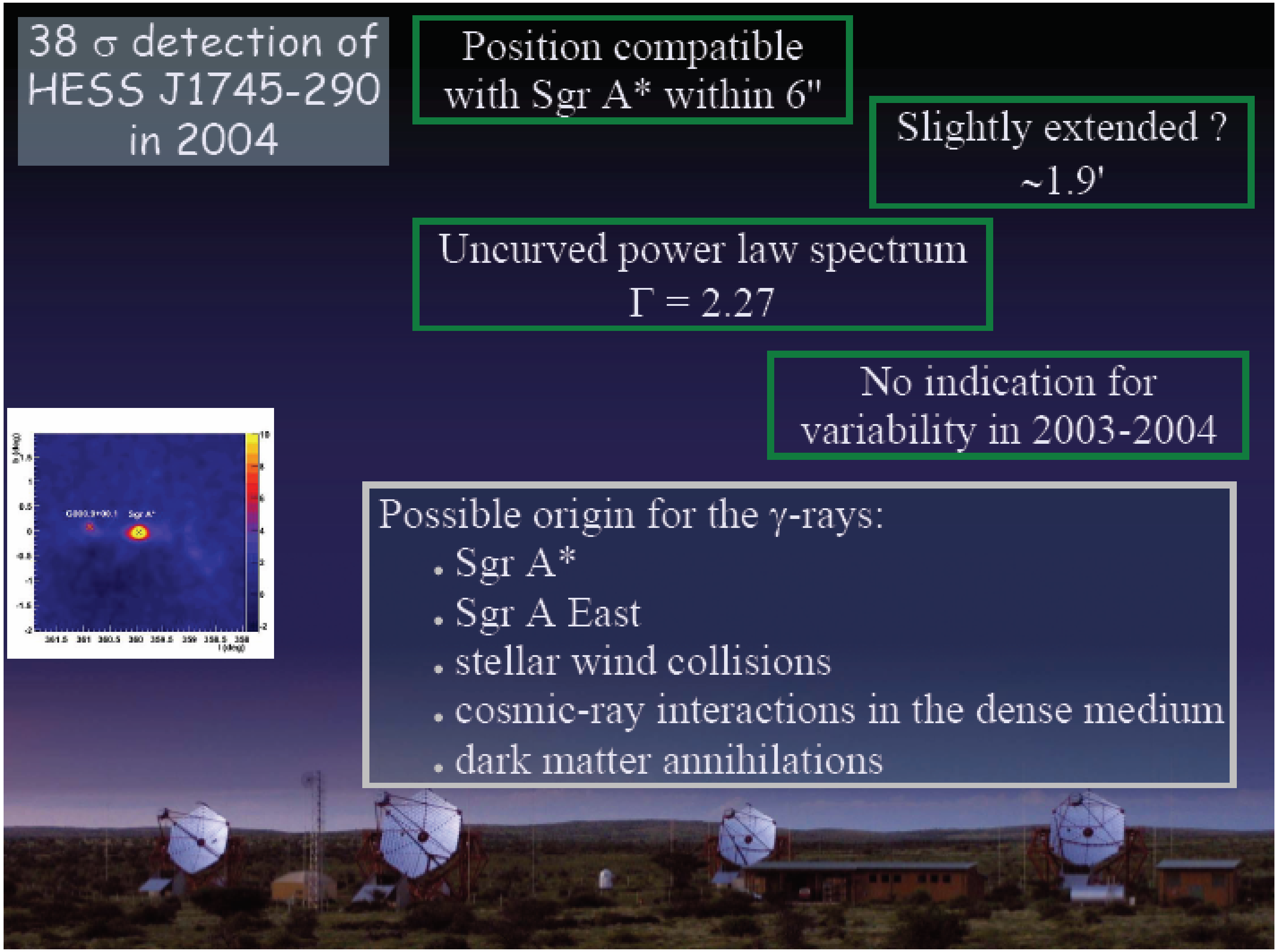
(in ~40 h obs. time distributed over 2 years)

Variability?

Nightly average flux

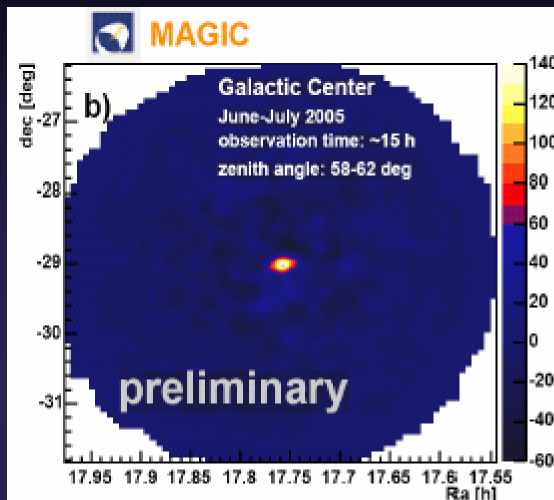
15% systematic errors added

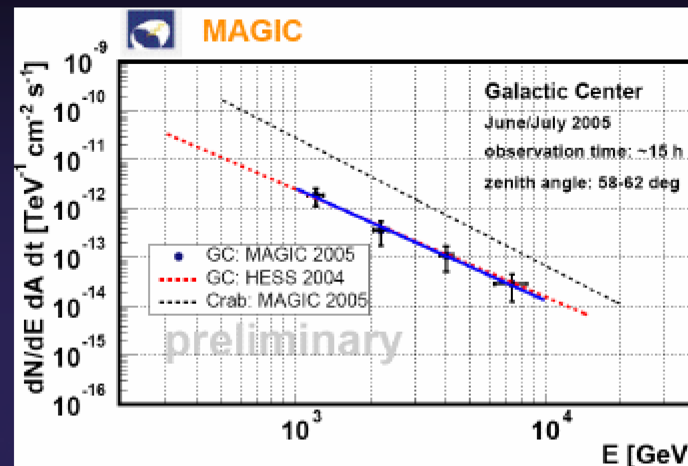



38 σ detection of HESS J1745-290 in 2004
Position compatible with Sgr A* within 6"
Slightly extended ? ~1.9'
Uncurved power law spectrum Γ = 2.27
No indication for variability in 2003-2004
Possible origin for the γ-rays:
• Sgr A*
• Sgr A East
• stellar wind collisions
• cosmic-ray interactions in the dense medium
• dark matter annihilations

Galactic Center clearly seen by MAGIC

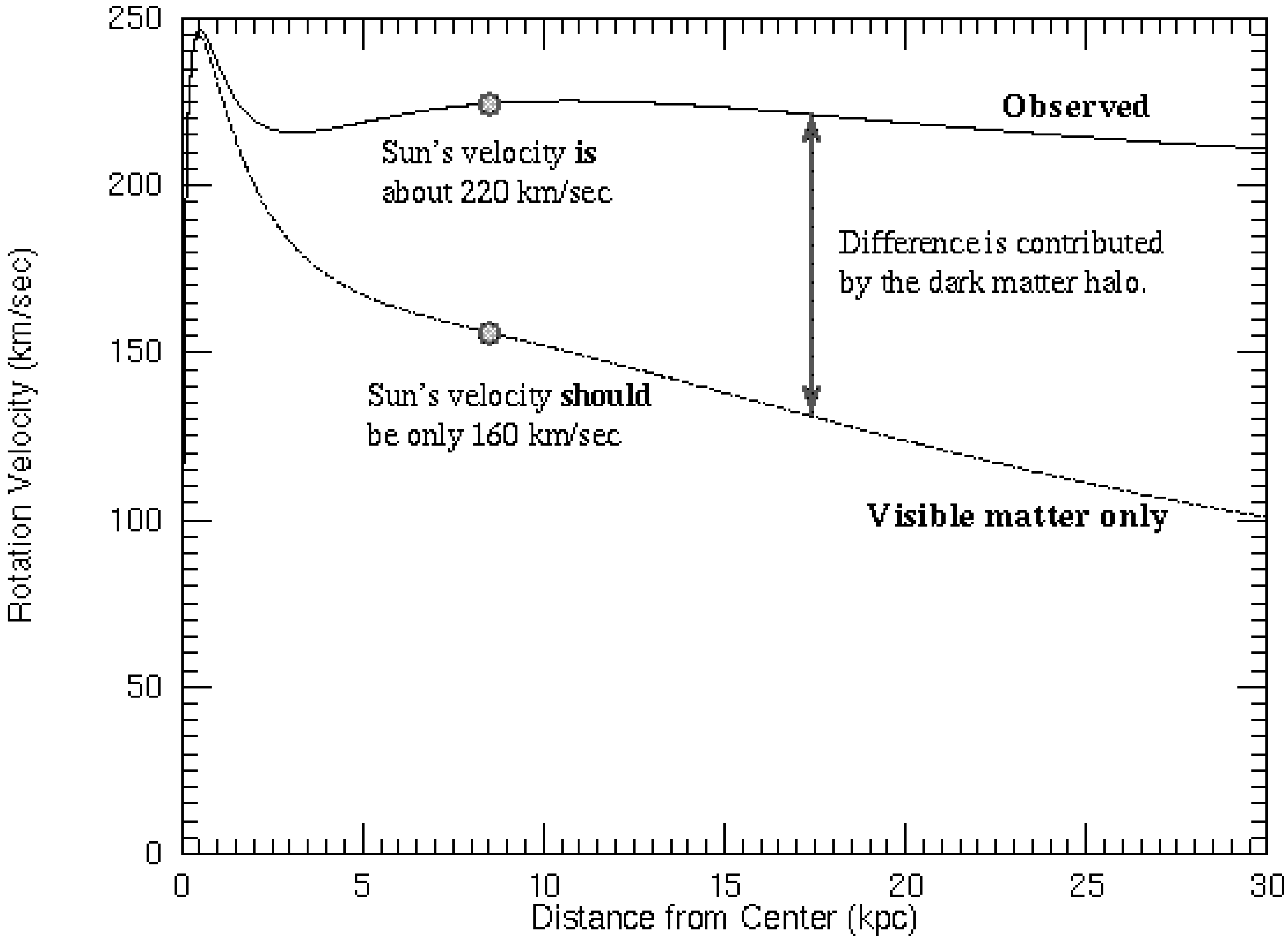
Spectrum



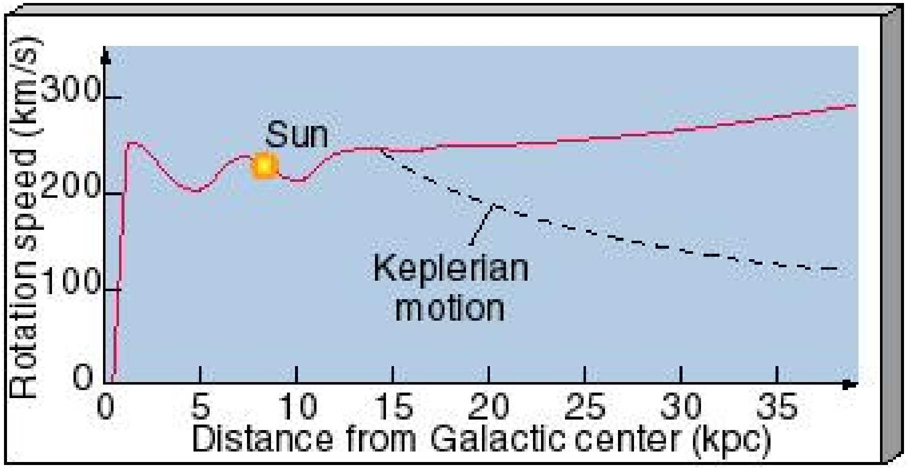


ICRC'05

Very assuring spectral agreement between H.E.S.S. and MAGIC!

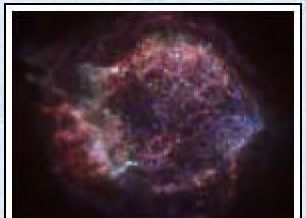


The gravity of the visible matter in the Galaxy is not enough to explain the high orbital speeds of stars in the Galaxy. For example, the Sun is moving about 60 km/sec too fast. The part of the rotation curve contributed by the visible matter only is the bottom curve. The discrepancy between the two curves is evidence for a **dark matter halo.**



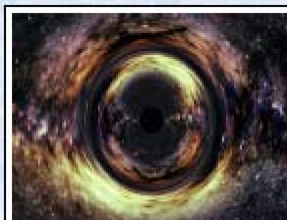
Rotation speed (km/s)
300
200
100
0
Sun
Keplerian
motion
0
5
10
15
20
25
30
35
Distance from Galactic center (kpc)

GR flux from the GC: Interpretations



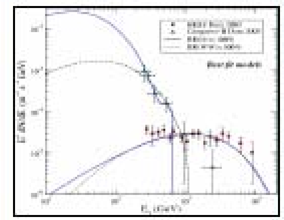
SNR Sgr A East

- SNRs are natural proton accelerators
- Energetic protons collide with the dense ambient matter
- HESS spectral index close to shock-accelerated particles



Central SMBH

- Protons & Electrons can be accelerated close to the accretion disk of the SMBH
- Protons produce TeV γ's through syncro. rad., collisions with ph. or p.
- Electrons produce TeV γ's through ICS off ambient γ's



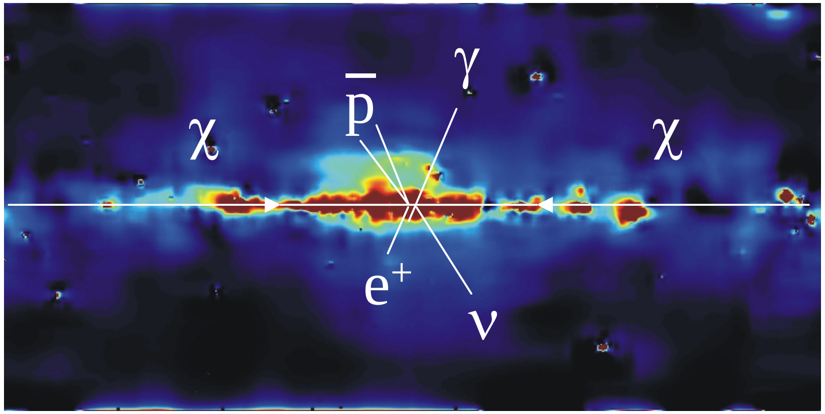
DM annihilations

- DM can be overdense in the GC
- If DM=WIMP's, pair ann. will produce π^0's from final products hadroniz.
- π^0's produce a continuum of γ's up to $E_\gamma = m_{WIMP}$

Methods of Weakly Interacting Massive Particle (WIMP) Dark Matter detection:

- **Discovery at accelerators (Fermilab, LHC,..)**
- **Direct detection of halo particles in terrestrial detectors**
- **Indirect detection of neutrinos, gamma rays, radio waves, antiprotons, positrons in earth- or space-based experiments**

The basic process for indirect detection is annihilation, e.g, neutralinos:



Indirect detection

Gamma Rays as a probe of DM

- Carry **directional information** (*point to the DM annihilation site*)
- Carry **spectral information** (*DM annihilation products/mass + GR line at* $E_\gamma \approx m_\chi$)

...but on the flip side of the coin...

- Suffer from largely unknown GR **background sources**
- The DM-induced fluxes depend **crucially** on the (poorly known) innermost structure of **DM halos**

INTEGRAL DATA (~2004)

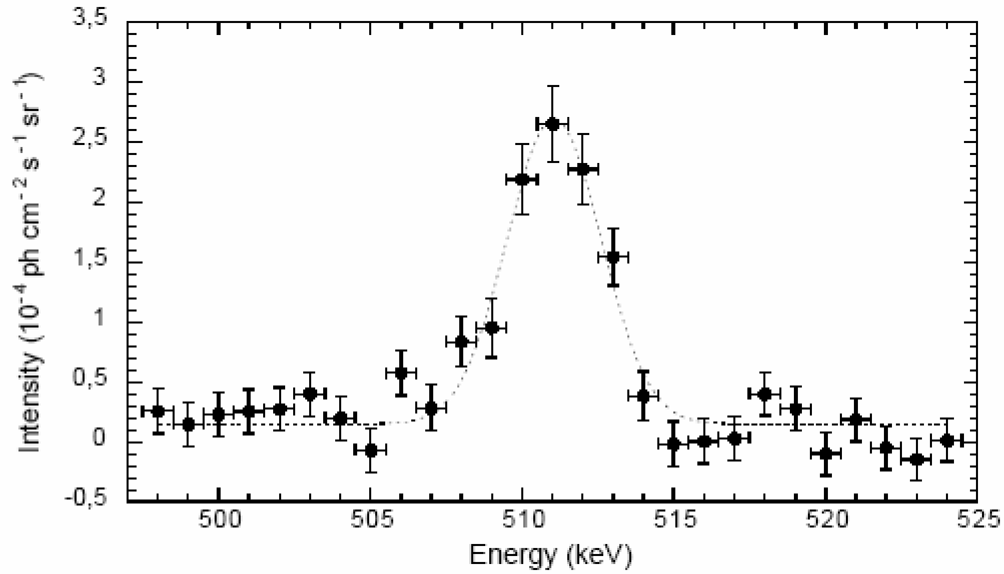
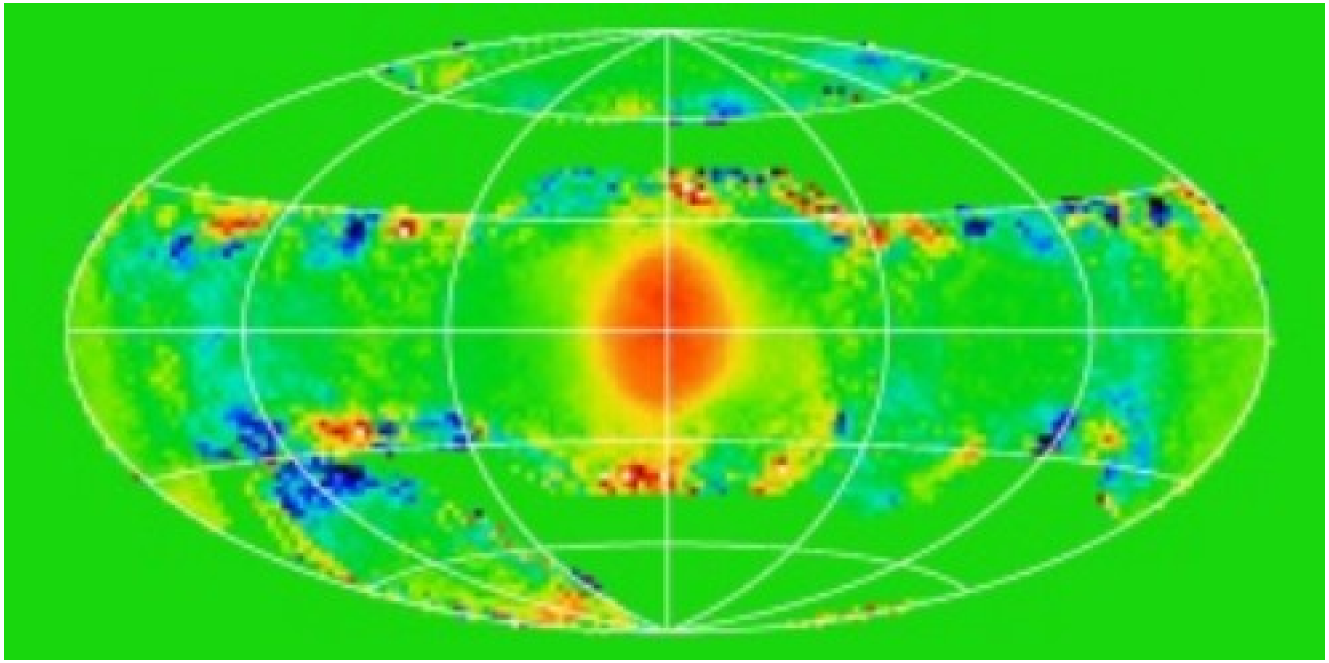


Fig. 3. 511 keV flux spectrum obtained using a gaussian centred on the GC with a FWHM of 10°.

Measured since early ‘’70s

Varaiability ?



The bulge emission is highly symmetric and is centred on the galactic centre with an extension of 8 deg.

Source - Type Ia supernovae and/or low-mass X-ray binaries

Also Light dark matter annhilation

The disk emission can be attributed to the beta+ decay of the radioactive species 26Al and 44Ti.

The Solar 2 Heliostat Array

Located 15 miles outside Barstow, CA

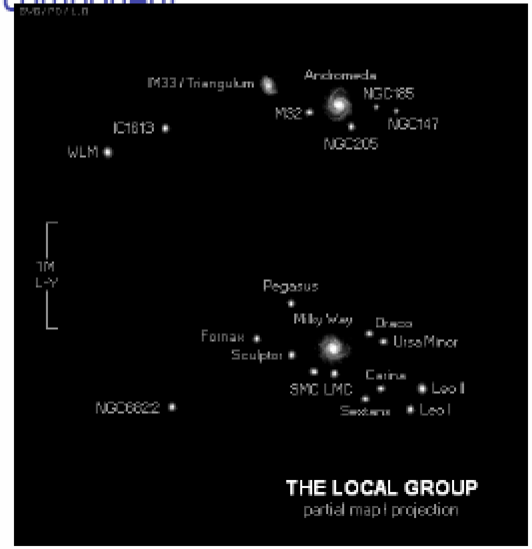
Over 1,900 42m^2 heliostats. The largest array in the world.

We have ~160 heliostats in the FOV of our camera.

Collection area = ~64,000 m^2.

Draco and Dark Matter

Draco is a dwarf spheroidal galaxy in the vicinity of the milky way. Its estimated total mass of is ~0.3 - 8 x 10^7 solar masses and, given the low luminosity of ~2 x 10^5 L_{solar}, the global mass-to-light ratio anywhere in the 10-100 range. This requires that Draco contain a dominant dark matter component.



Draco is about 0.5 degrees across. It is very faint in the optical.

Integrated magnitude ~11 making it an ideal candidate for ACT observations.

Neutralinos: Previous attempts at understanding Draco.

Neutralinos are the lowest mass supersymmetric particles in the Minimum SUSY Model. Since they are stable, they are a popular candidate for Cold Dark Matter.

Neutralinos can annihilate into quark and anti-quark pairs. The resulting hadron jets will contain gammas from neutral pion decays.

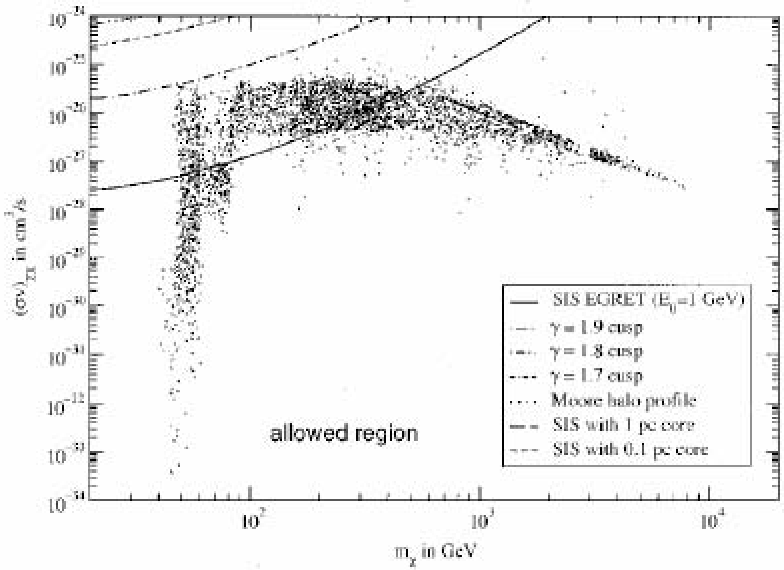
The rate will depend on ρ^2, where $\rho \sim r^{-\gamma}$ is the density profile of the neutralinos.

PHYSICAL REVIEW D **66**, 023509 (2002)

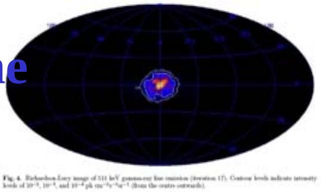
Particle dark matter constraints from the Draco dwarf galaxy

Craig Tyler*
Department of Astronomy & Astrophysics, The University of Chicago, Chicago, Illinois 60637

(Received 18 March 2002; published 3 July 2002)

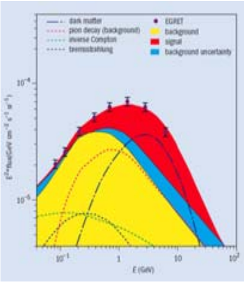


• The MeV-scale Dark Matter particle giving the 511 keV annihilation line at the galactic center



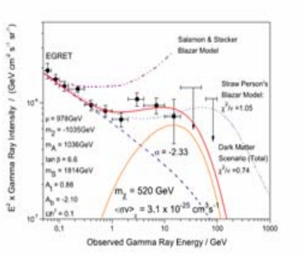
Integral

• The 50 – 70 GeV neutralino Dark Matter particle which explains the EGRET galactic gamma ray spectrum



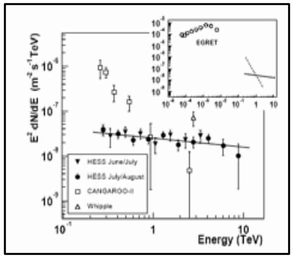
W. de Boer

• The 500 GeV neutralino Dark Matter particle which explains the EGRET extragalactic gamma ray spectrum



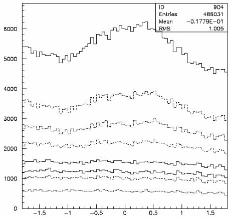
Elsässer & Mannheim

• The 20 TeV Dark Matter particle giving the HESS signal from the galactic center



HESS

• The few hundred GeV Dark Matter particle in Draco giving the signal in CACTUS

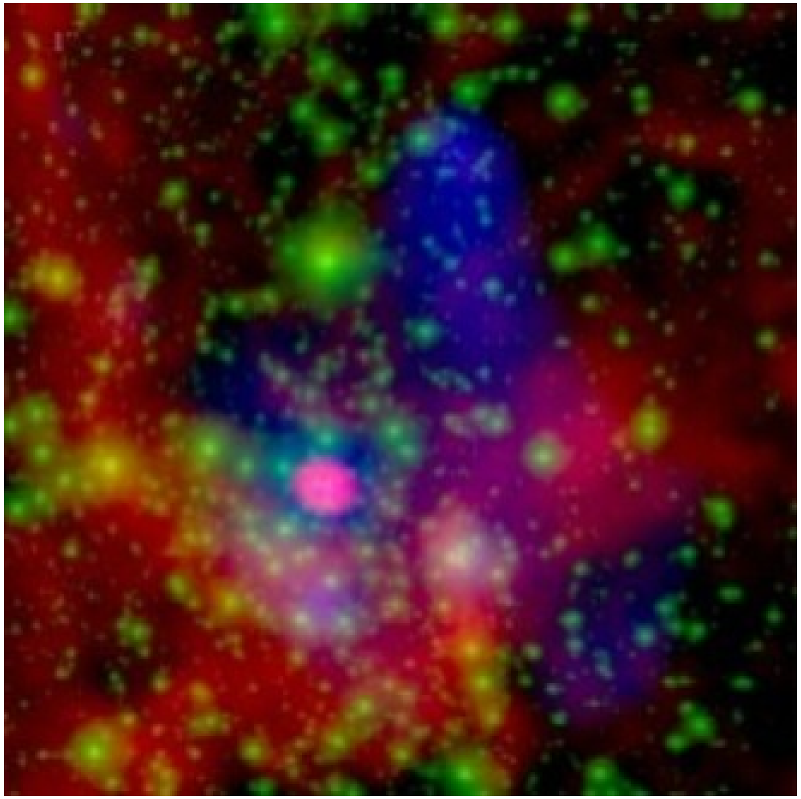


CACTUS Collab.

Conclusions

- The existence of Nonbaryonic Dark Matter has been definitely established from cosmological measurements.
- CDM is favoured (e.g., supersymmetric particles).
- Indications of gamma-ray excess from galactic center, the galactic halo, the extragalactic flux and perhaps from the Draco dwarf galaxy. However, none compelling (at least to this speaker). Need more definitive spectral signature – the gamma line or a sharp drop at $E_\gamma = m_{DM}$ would be a ”smoking gun”.
- Where does the GeV excess in galactic and extragalactic gamma-rays come from? GLAST data will be crucial.
- The hunt is going on – many new experiments (GLAST, VERITAS, AMS) are coming on soon!
- Complementarity: GLAST will do all-sky search for ”hot spots” with high sensitivity – ACTs may do small-angle, detailed study.
- ACTs will soon have interesting data on dwarf galaxies.
- LHC starts within 2 years…

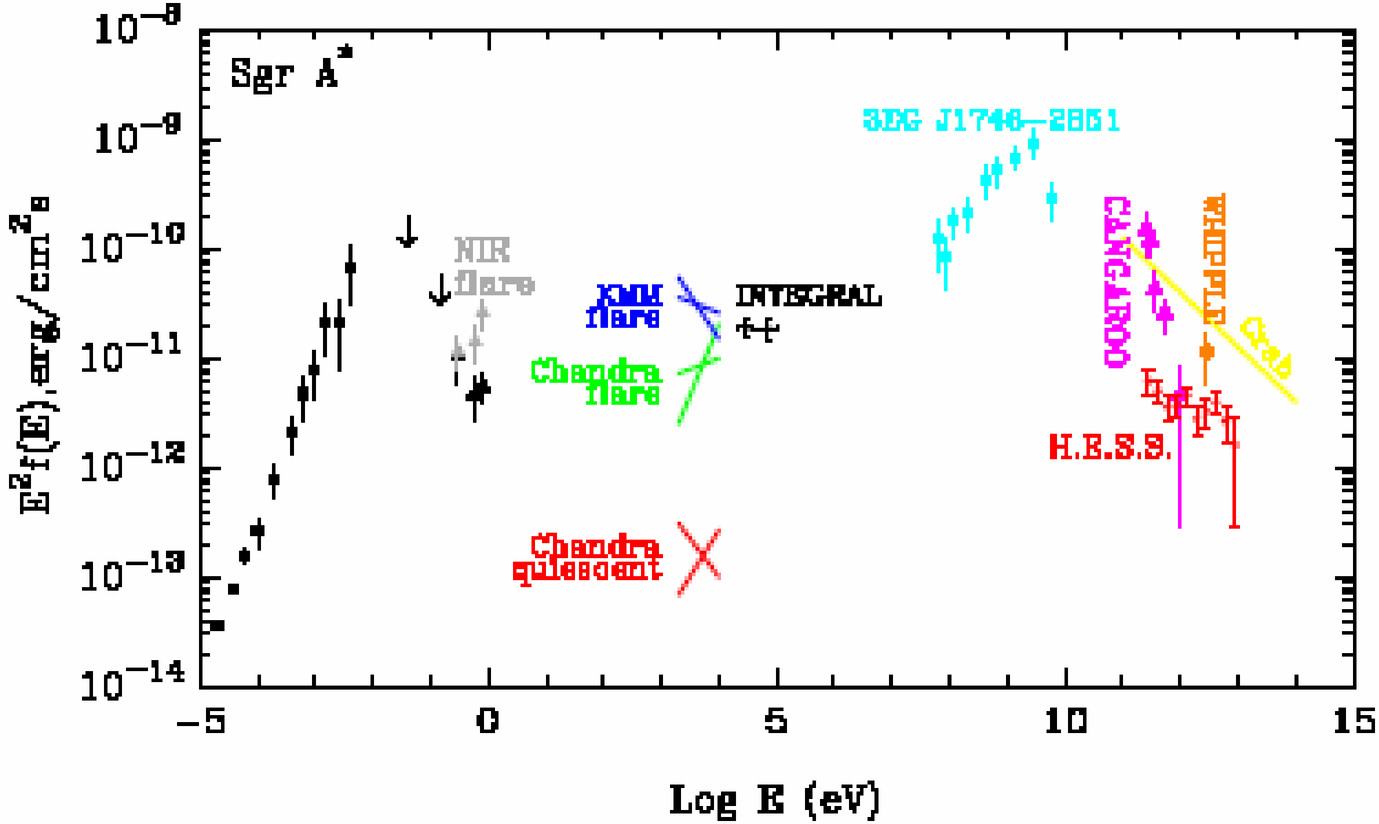
Possible Pulsar (x-rays) G359.95-0.04(Dec 05)



PWN (blue)within Hess error bax – ~ 1 LY from Sgr A*(pink)

Galactic Center (HESS)

- **1. Flux – 5% of crab flux**
- **is consistent with constant emission – hours/days/months/years – vicinity of Sgr A* (SMBH) ruled out**
- **2. Spectrum is a pure power law(-2.2) – does not match (curved spectrum) expected from DM(neutralino) annhilation**



Sgr A*
3EG J1746−2851
NIR flare
XMM flare
INTEGRAL
Chandra flare
Chandra quiescent
CANGAROO
WHIPPLE
Crab
H.E.S.S.
$E^2 f(E)$, ergs/cm^{2}s
Log E (eV)

A cosmic-ray source uncovered

Scientists in the HESS collaboration have observational evidence of cosmic rays coming from our galaxy's center.. This is the first time scientists have found direct evidence for accelerated cosmic rays.

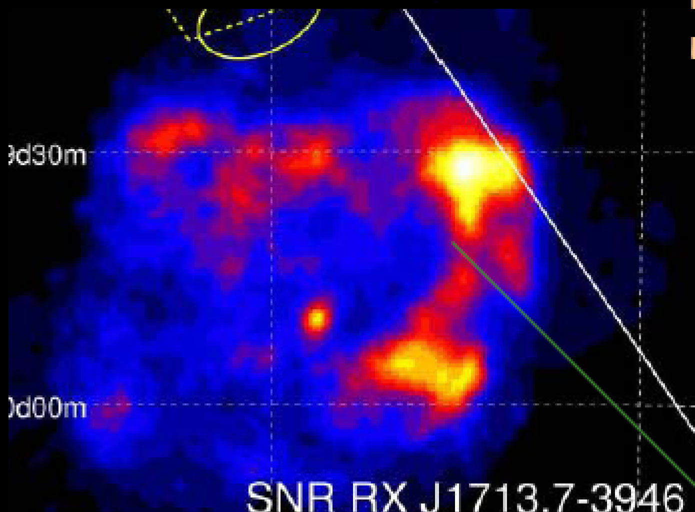
Two possible cosmic-ray accelerators reside in the galactic center. . More observations are needed to pinpoint which is the cosmic-ray source.

Cosmic Ray Accelerators ?

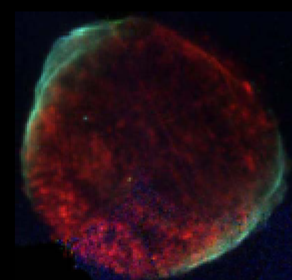
SNRs in our Galaxy: 231(Green et al. 2001

with nonthermal X-ray emission –

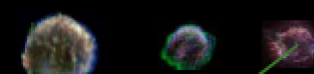
best candidates - young SNRs with nonthermal synchrotron X-rays



SN1006



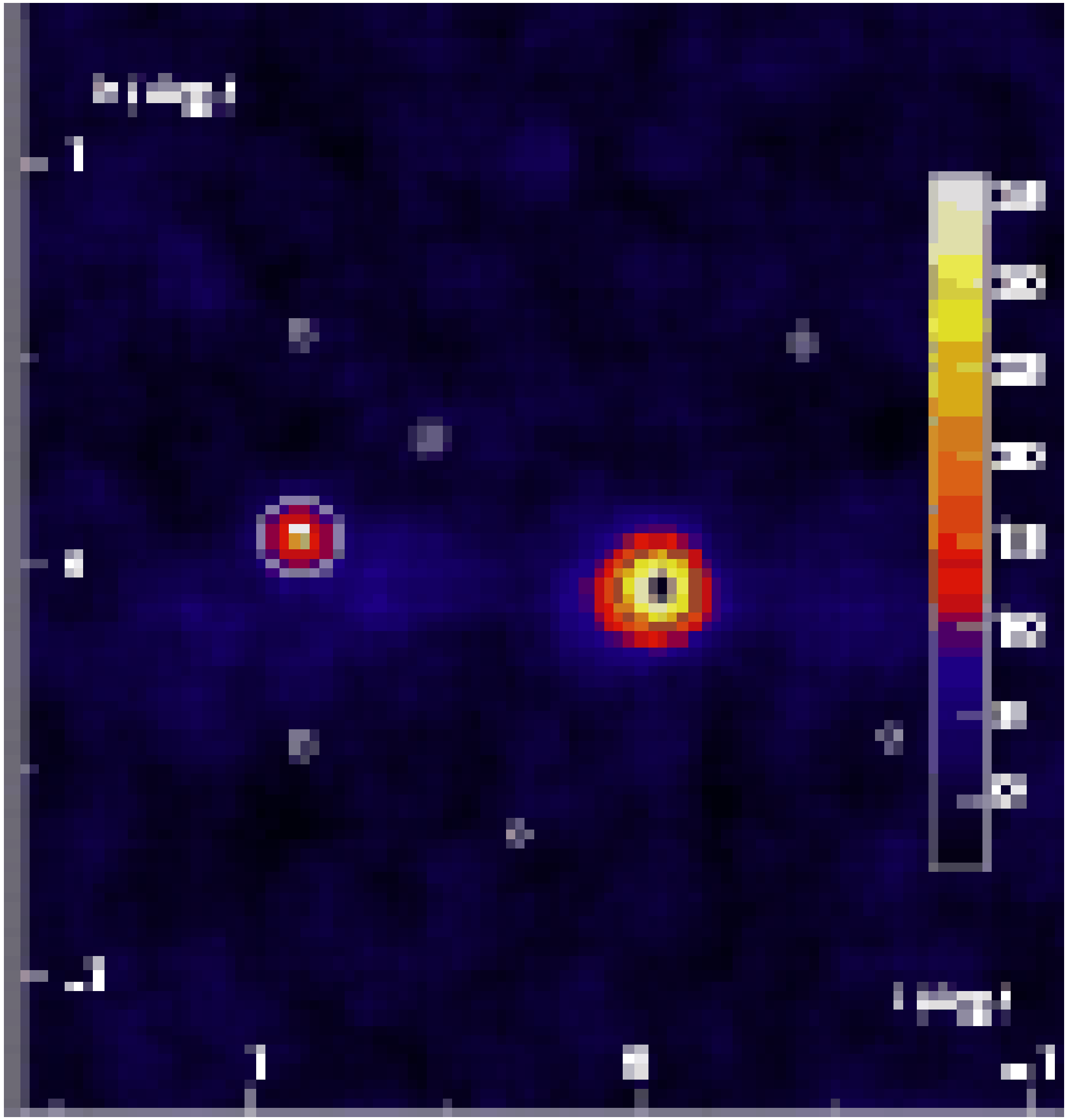
Tycho Kepler CasA

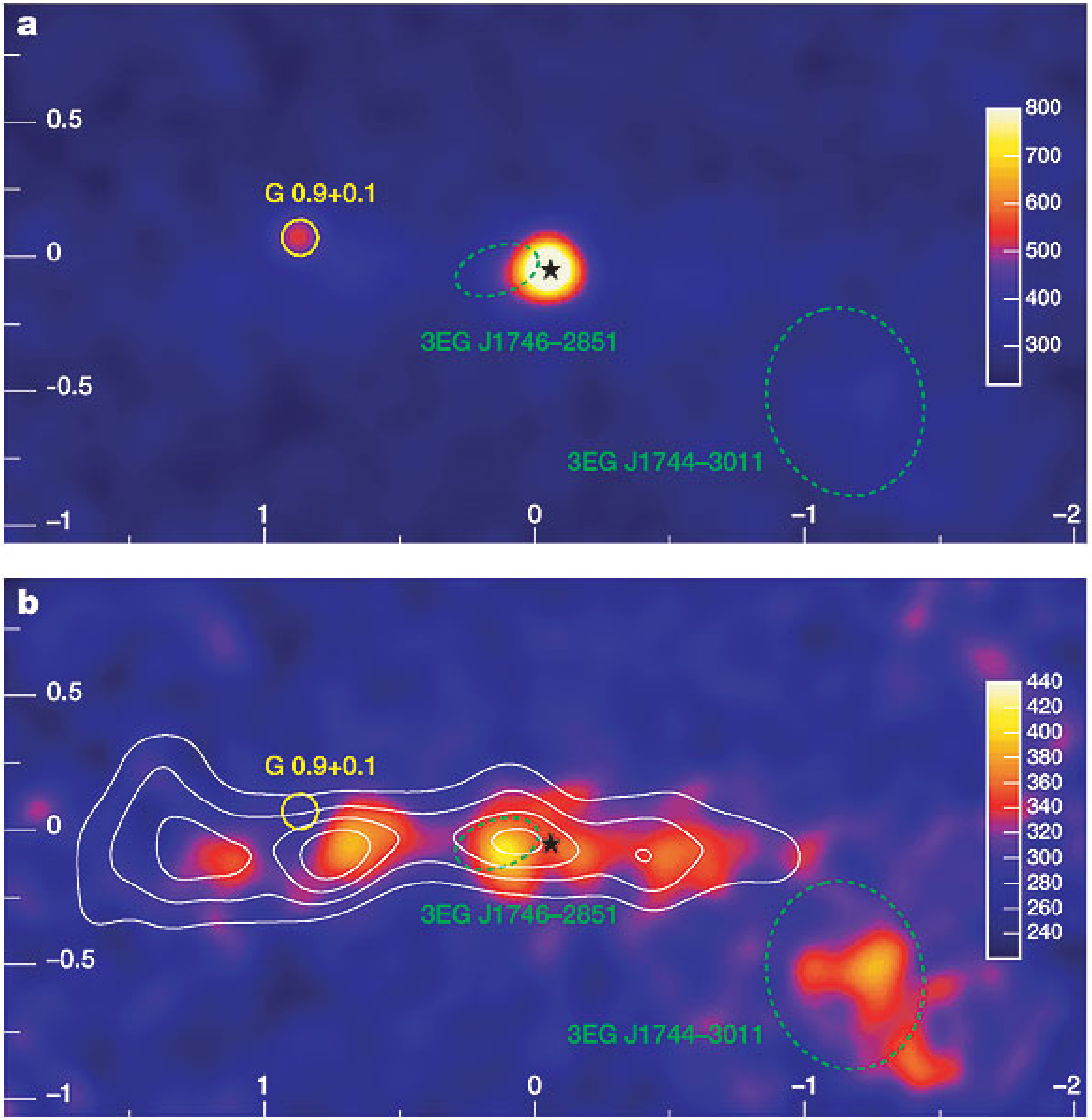


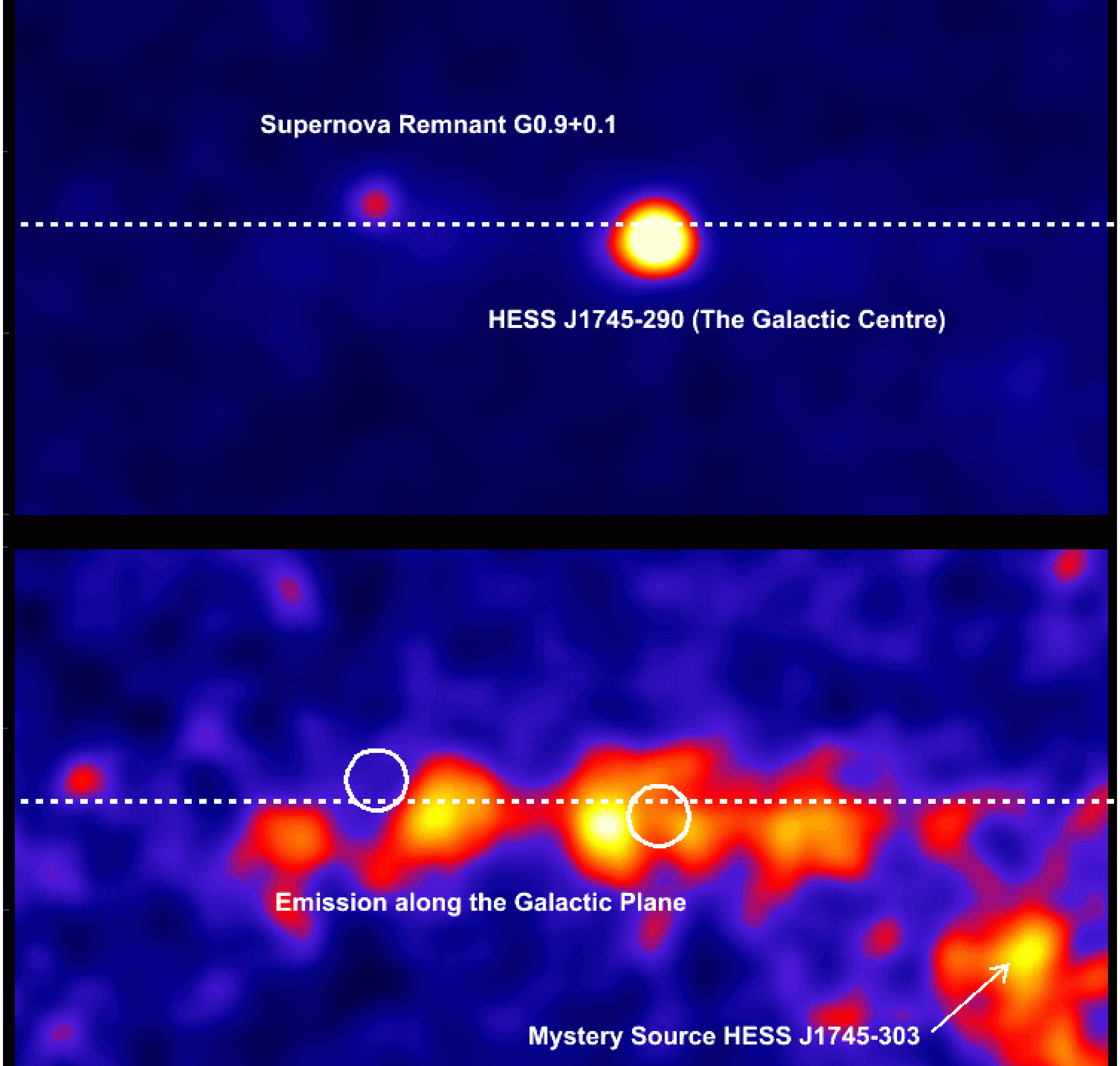
30 arcmin

TeV emission

H.E.S.S. PSF




a
0.5
0
−0.5
−1
1
0
−1
−2
G 0.9+0.1
3EG J1746−2851
3EG J1744−3011
800
700
600
500
400
300
b
0.5
0
−0.5
−1
1
0
−1
−2
G 0.9+0.1
3EG J1746−2851
3EG J1744−3011
440
420
400
380
360
340
320
300
280
260
240


Supernova Remnant G0.9+0.1
HESS J1745-290 (The Galactic Centre)
Emission along the Galactic Plane
Mystery Source HESS J1745-303

After subtraction of point sources:

(55 hrs data - 3500 photons – 14.6 sigma)

(1)Extended emission spatially coincident with Egret Unid. Source

(2) Emission along gal. Plane for ~ 2 degrees

Eng Thresh ~ 380 GeV

The recons. Gamma ray spectrum
slope = 2.29 +/- .07 +/- .2

2 degrees >> 30 pc
ISM – Giant Molecular clouds in the region
17-44 mil solar masses
Close match between density of interstellar gas (traced by CS emission) and VHE gamma ray emission

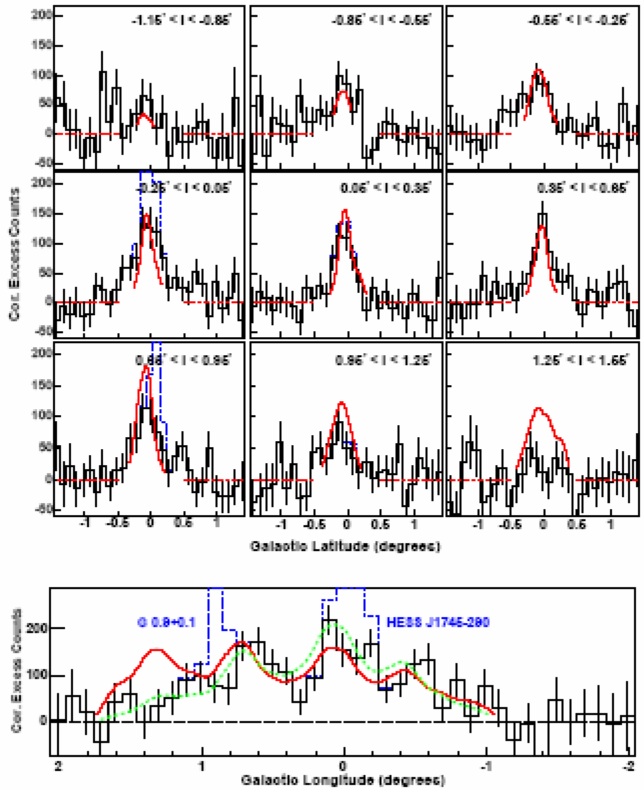
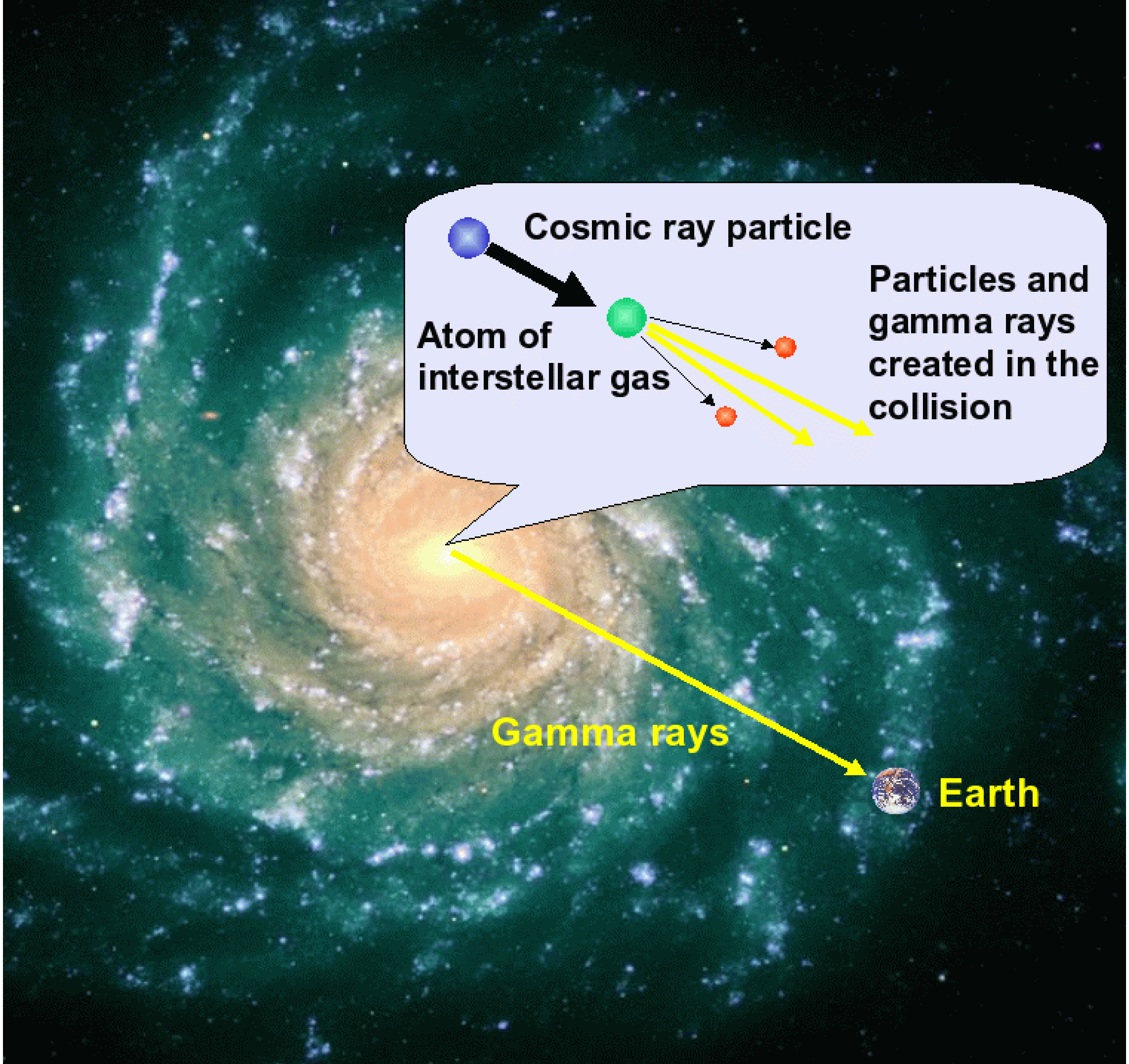


Figure 2: Distribution of γ-ray emission in Galactic latitude (for individual slices in longitude, top) and in Galactic longitude (bottom). The red curves show the density of molecular gas, traced by CS emission. The upper curves show acceptance corrected (and cosmic-ray background subtracted) γ-ray counts for $0.3°$ wide bands in longitude. The point-source subtracted counts are shown in black. The dashed blue histogram shows the unsubtracted values (the y-scale is truncated). The red curves correspond to the smoothed CS map of Fig. 1 and are drawn only in the regions where CS measurements are available. The dashed red lines show nominal zero CS density in regions away from the Galactic plane. The lower plot shows γ-ray counts versus l for $-0.2° < b < 0.2°$. The CS line flux may be underestimated close to $l = -1°$ due to a narrower coverage in b at this longitude. The dashed line shows the γ-ray flux expected if the CR density distribution can be described by a Gaussian centred at $l = 0°$ and with rms $0.8°$, as expected in a simple model for diffusion away from a central source of age $\sim 10^4$ years. In all plots the background level is estimated using events from the regions $0.8° < |b| < 1.5°$. Error bars show ± 1 standard deviation.


Cosmic ray particle
Atom of interstellar gas
Particles and gamma rays created in the collision
Gamma rays
Earth

Close correlation between target material and gamma rays > Strong indicator for origin in Cosmic ray interactions !

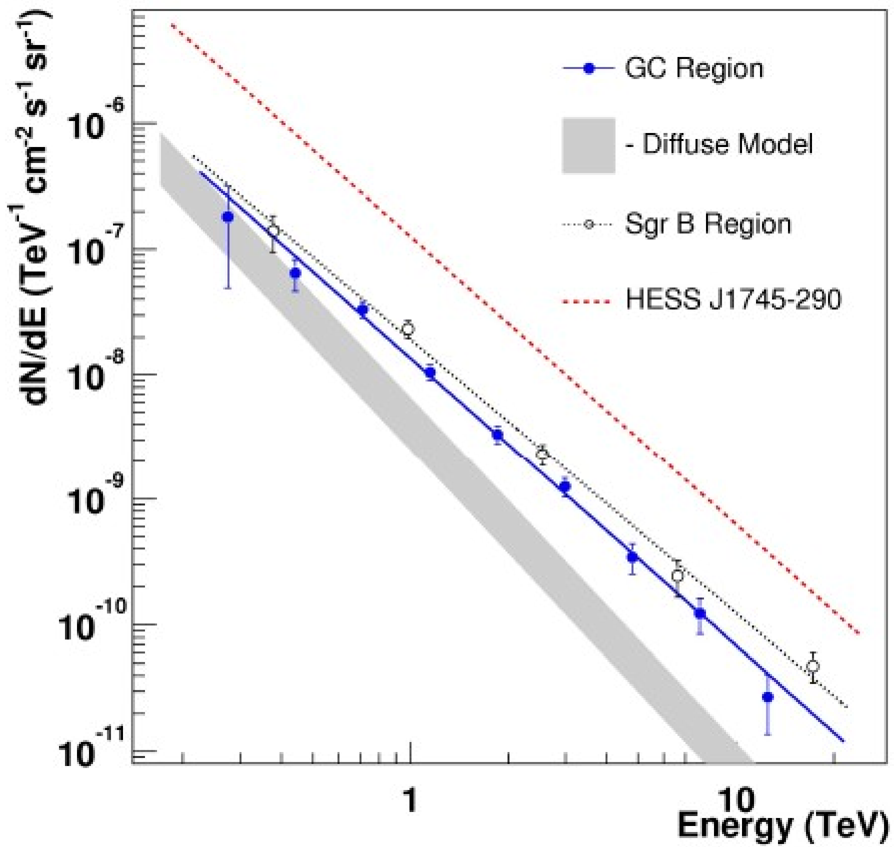
Measured spectrum HARDER than obsvd on earth (2.3 >> 2.7) . Propagation effects less pronounced because accelerator nearby

Expected. And Obsvd agree < 500 GeV

But At > 1 TeV 3-9 higher than expected Flux

(For electron sources Inv Compton scattering

Intense photon/magnetic fields)



Diff model – solar neighbourhood data

(1) To give gammas of 4-40 TeV we need 10**50 ergs; SN can give 10**51.Therefore 10 % of explosion for accelerating cosmic rays (Theory – Cr originate in shock wave of expanding SNRs)

(2) Must have occurred in recent past since it has not diffused out . Calculations give ~ 10 kyr

(3) Gamma ray spectrum is hard – protons+mater > gamma rays . More likely to be protons

Cosmic Ray Source ?

- Within the 1' error box of HESS J1745 - 290 are two compelling candidates for such a galactic cosmic-ray accelerator.
- (a)SNR Sgr A East with its estimated age around 10 kyr
- (b)A Supermassive BH Sgr A* which may have been more active in the past
- Potential of Gamma Ray Astronomy finally realized !

Cosmic/Gamma Rays + GC

(1) **GLAST – should establish definitively which GC object is giving ~GeV gamma**

(2) **Cerenkov telescopes - Need continued monitoring of GC at ~GeV/TeV . More Cosmic ray sources ?**

(3) **AUGER - Massive increase in EHE CR data down to ~10^{18} eV. *Should see strong, GC point source of CRs and halo***

FUTURE OF GC ASTRONOMY

NASA newsletter – July 19,2006

Rough and crowded neighborhood at galactic center

The center of the Milky Way is a crowded neighborhood and not always a calm one, according to the latest image from NASA's Chandra X-ray Observatory.

INTEGRAL > Sgr A* may get bright in the near future

Galactic Centre will always be in News !

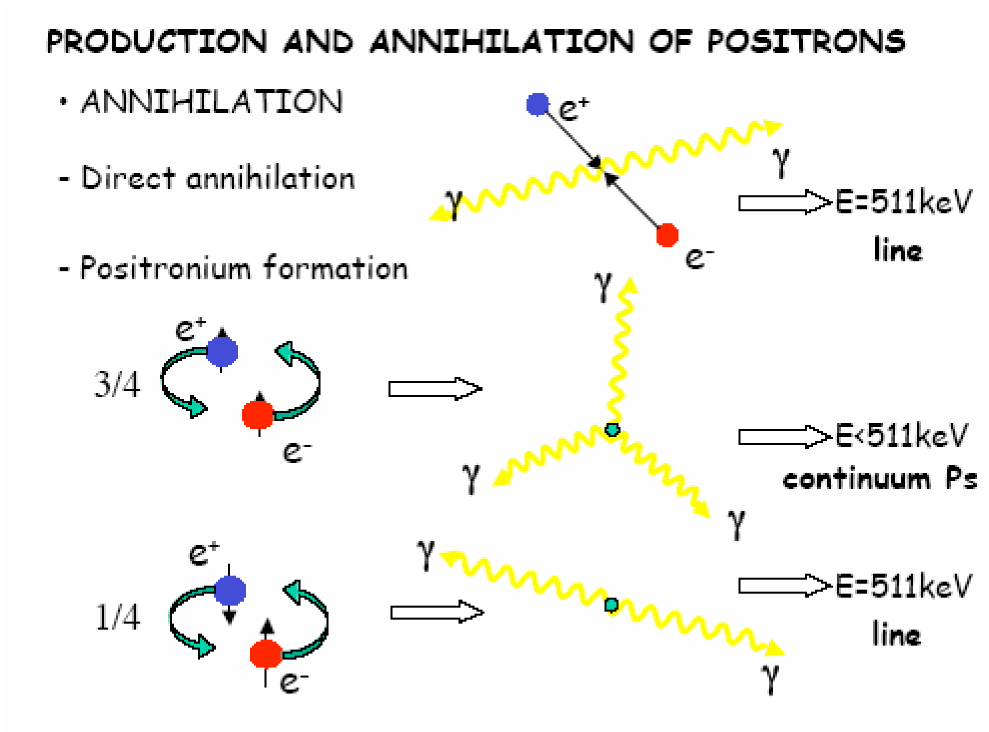
PRODUCTION AND ANNIHILATION OF POSITRONS

• PRODUCTION

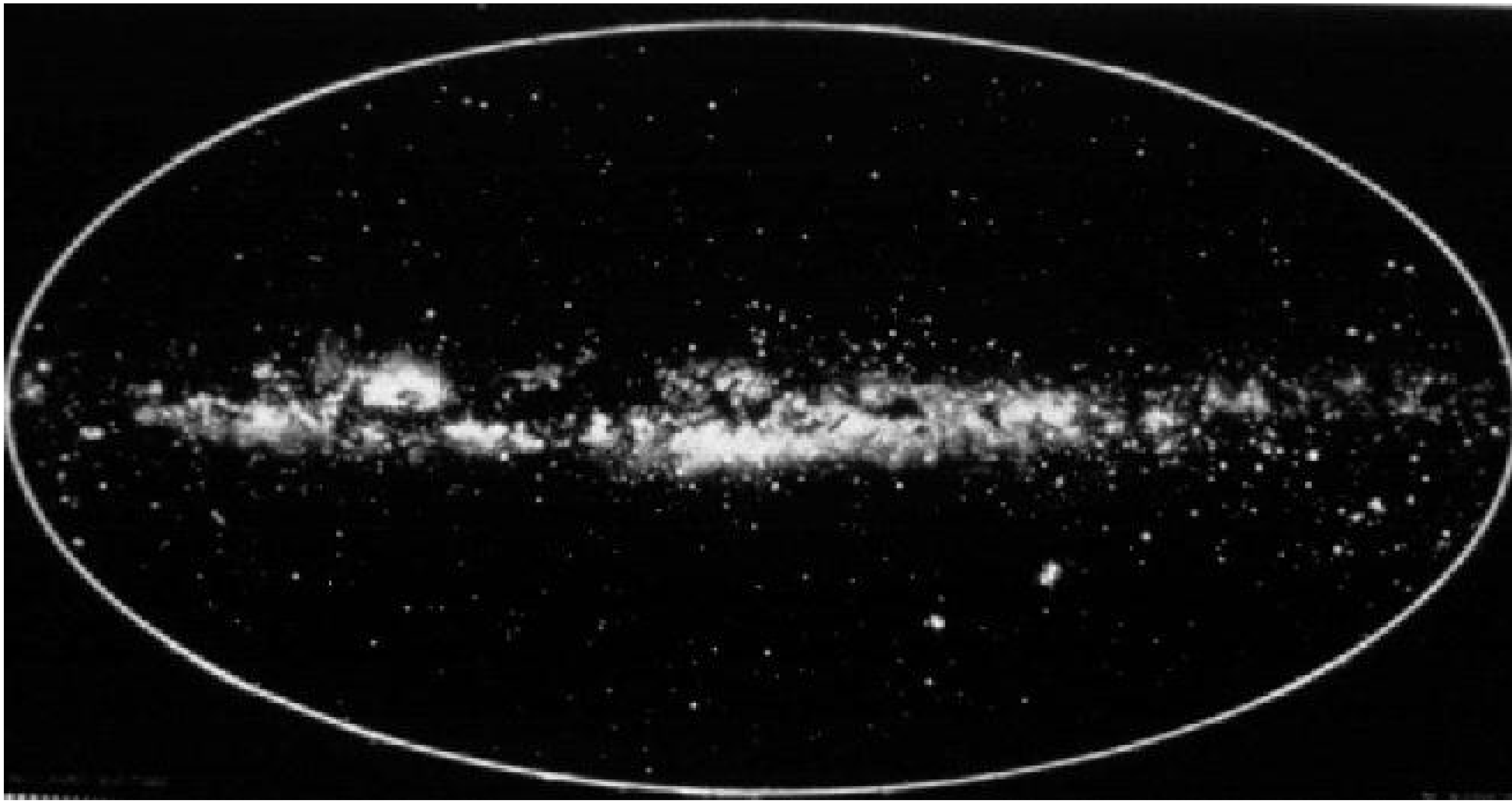
- β^+ isotopes -> SNe, Novae, CR...
  $T_{e+} \sim 0.1\text{-}1$ MeV

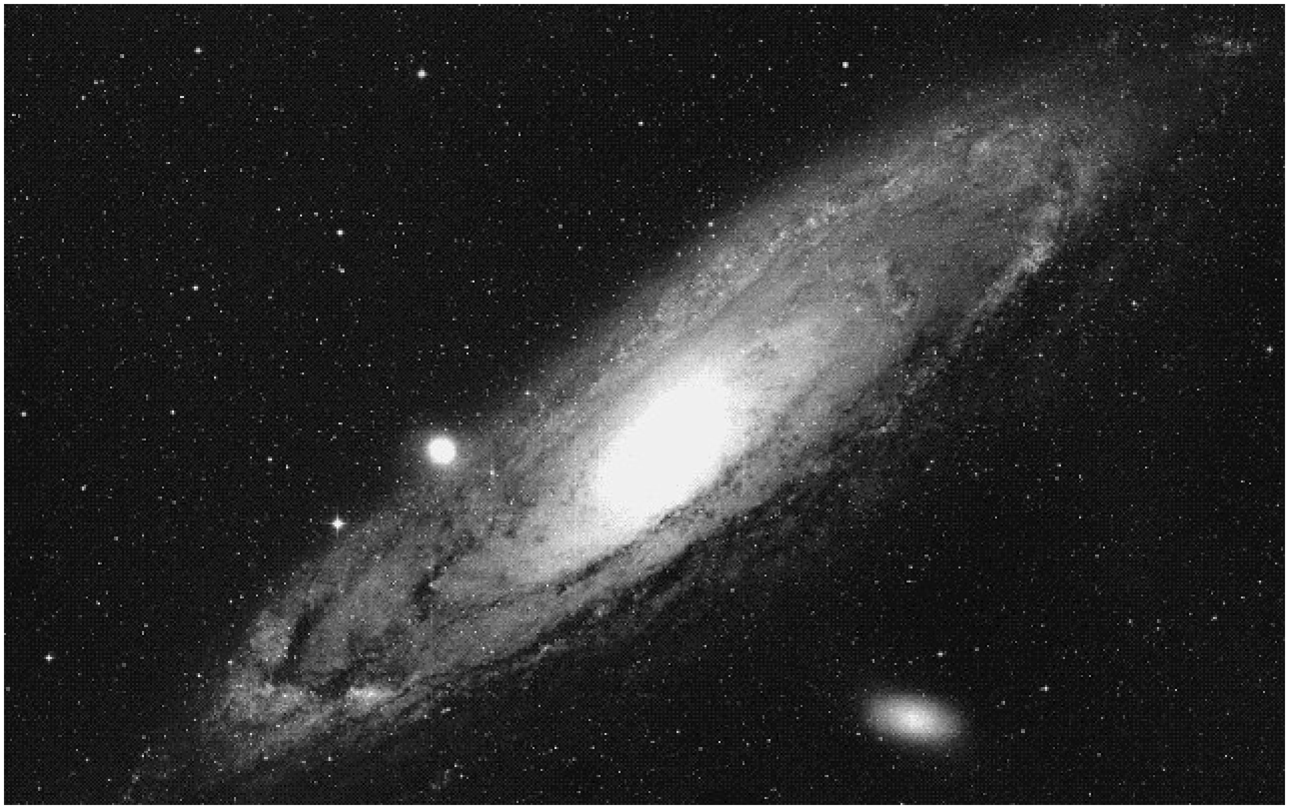
- π^+ decay -> CR interactions with ISM
  $p + p \rightarrow p + n + \pi^+$
  and $\pi^+ \rightarrow \mu^+ \rightarrow e^+$
  $T_{e+} \sim 10\text{-}100$ MeV

- e^+e^- pair production -> compact objects
  $\gamma + X \rightarrow X + e^+ + e^-$

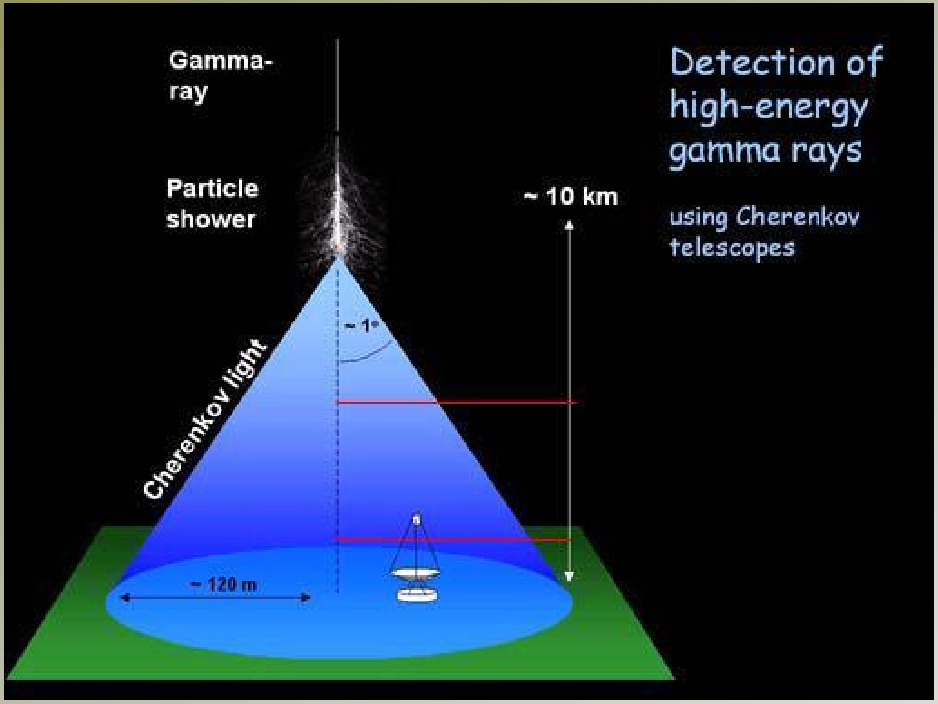


PRODUCTION AND ANNIHILATION OF POSITRONS
• ANNIHILATION
- Direct annihilation
e+
γ
γ
e-
E=511keV
line
- Positronium formation
3/4
e+
e-
γ
γ
γ
E<511keV
continuum Ps
1/4
e+
e-
γ
γ
E=511keV
line



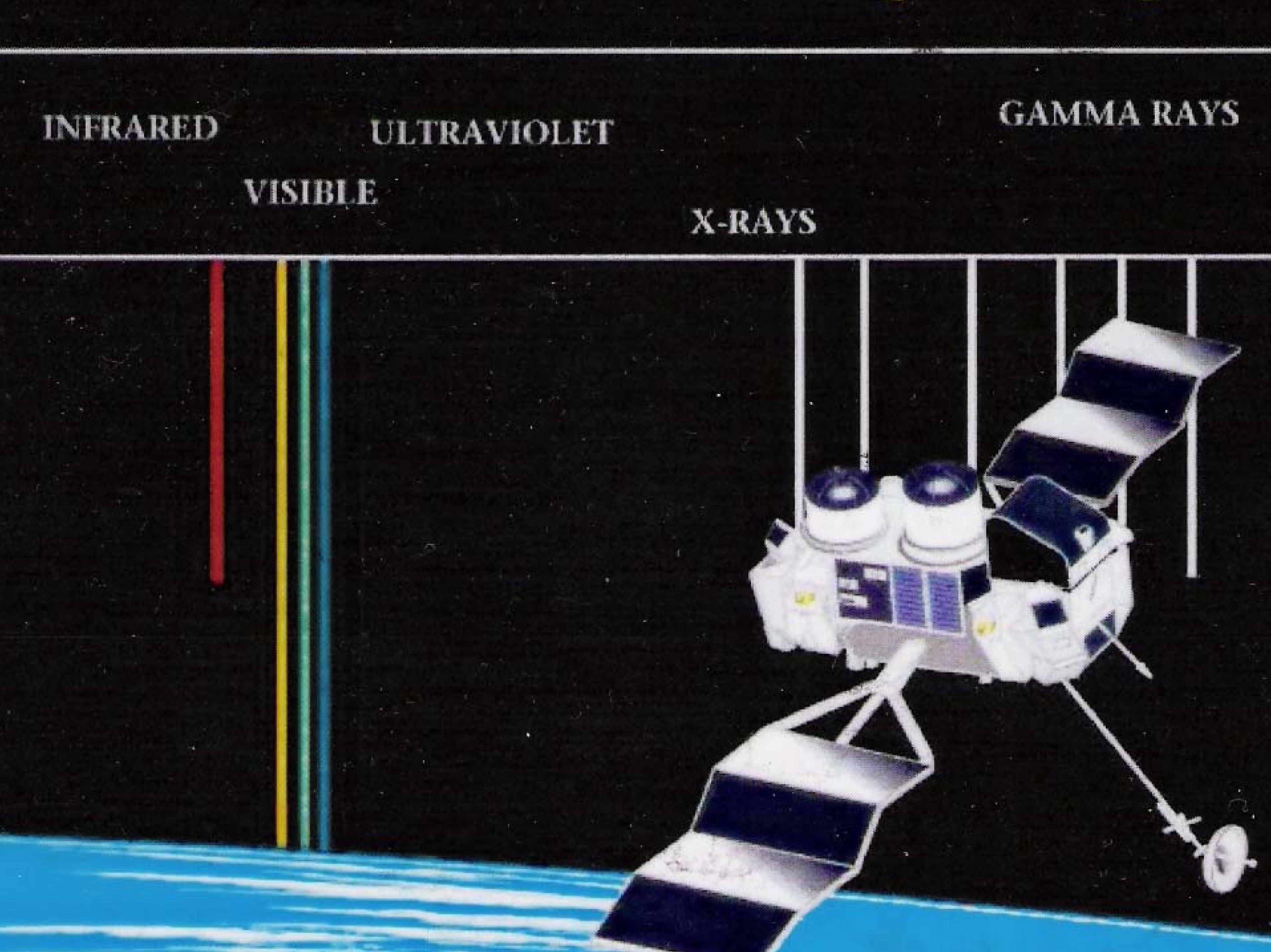


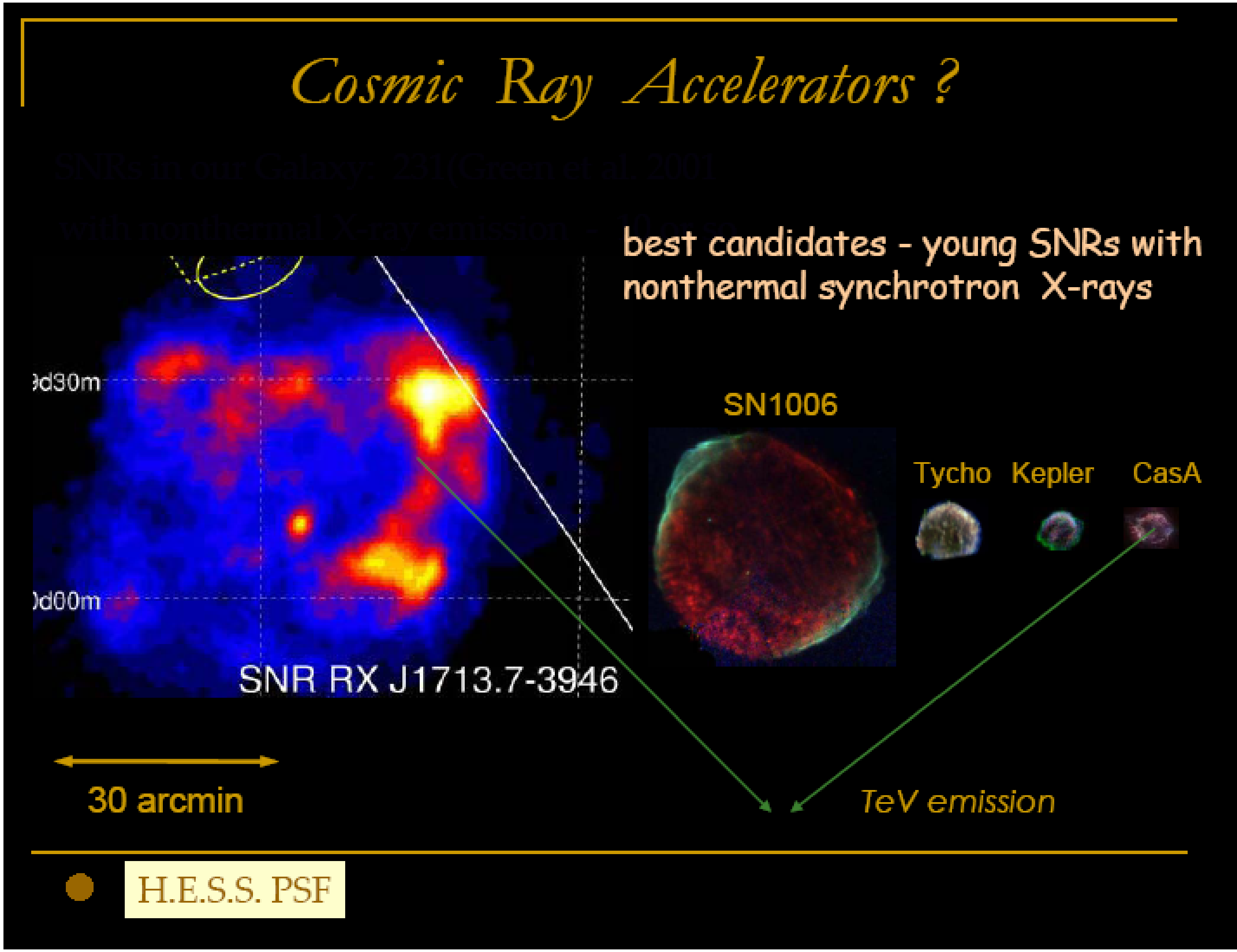
Atmospheric Cerenkov Technique



Collection area for ACT ~ 10^4 *m^2*

Collection area for satellite experiments ~ 1 *m^2*


INFRARED
ULTRAVIOLET
GAMMA RAYS
VISIBLE
X-RAYS


Cosmic Ray Accelerators ?
best candidates - young SNRs with nonthermal synchrotron X-rays
9d30m
0d00m
SNR RX J1713.7-3946
SN1006
Tycho
Kepler
CasA
30 arcmin
TeV emission
H.E.S.S. PSF