

# Seamless Astronomy

*Alyssa A. Goodman*

*Harvard-Smithsonian Center for Astrophysics  
Initiative in Innovative Computing @ Harvard*

*Key Collaborators:*

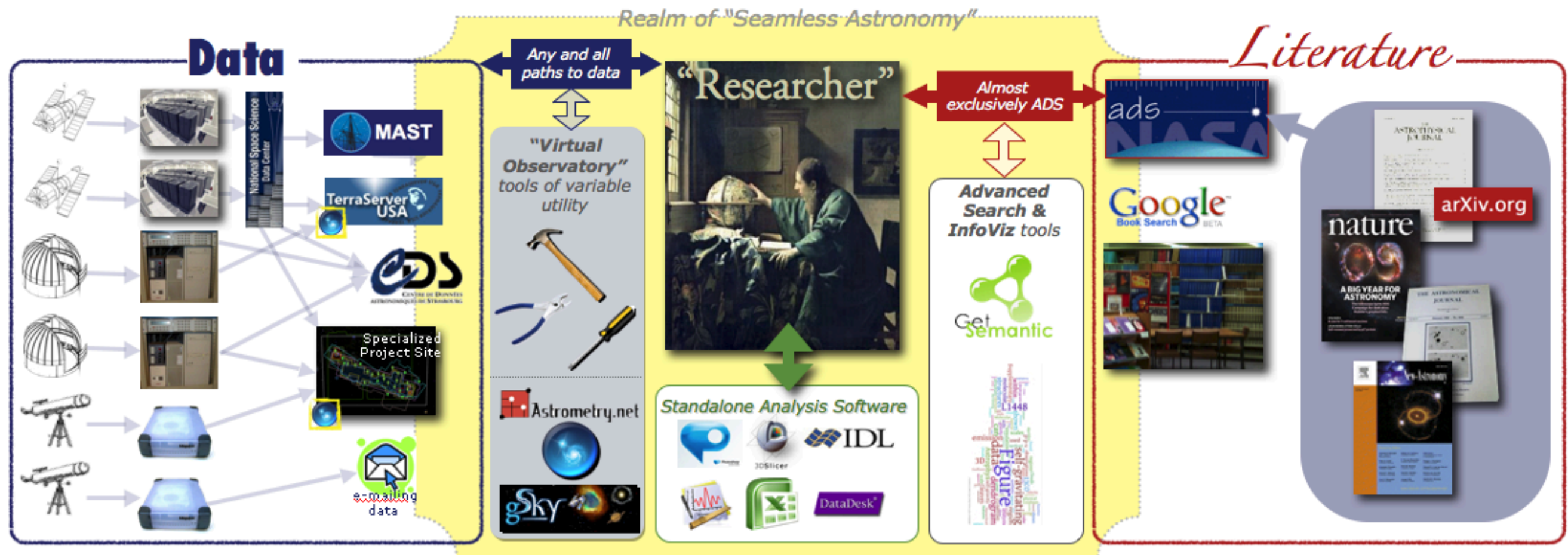
*Curtis **Wong** & Jonathan **Fay**, Microsoft Research/WWT  
Gus **Muench**, Harvard*





# Seamless Astronomy

[www.cfa.harvard.edu/~agoodman](http://www.cfa.harvard.edu/~agoodman) and [worldwidetelescope.org](http://worldwidetelescope.org)



Talk = overall philosophy  
Poster = a bit more rigor



# What (the) “Virtual Observatory” meant/means/should mean to...

Jim Gray & Alex Szalay

Typical Astronomers Today

Me

Astronomers who travel & use facebook...



# astrobitz?

terabitz every bit on real estate

Getting Started | Sign In

Enter Location

Street

optional

City, State or Zip

Ocala, FL

Go

[filter listings](#)

Drag and Drop icon to  
workspace below

Listings

Local

Market

Education

Safety

Financing

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Misc

Google  
Local  
Search

Local  
Photos

Airports

Banks

Cafes

Cinemas

Fast Food

Gas Stations

Grocery  
Stores

Health Care

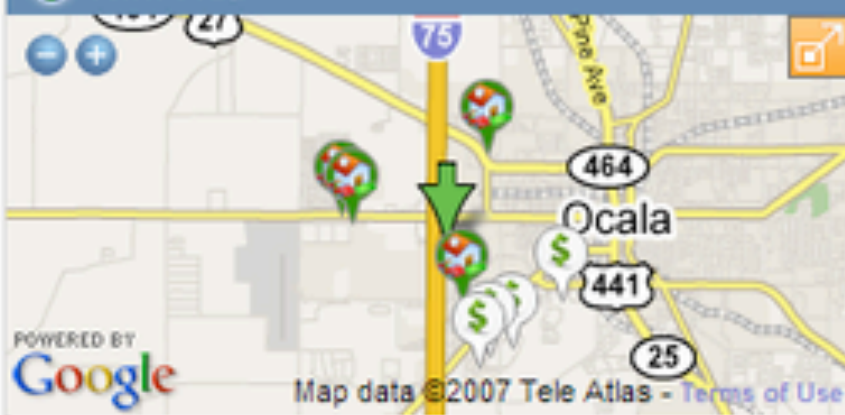
Libr

Take Snapshot

Dashboard

Map

Mini Map



For Sale Listings

2-Br 1-Ba	\$ 49,900
3116 Nw 17th St, Ocala, FL 34475	
3-Br 2-Ba	\$ 109,900
375 Nw 55th Ave, Ocala, FL 34482	
3-Br 2-Ba	\$ 124,900
280 Nw 53rd Ct, Ocala, FL 34482	
2-Br 2-Ba	\$ 150,000
3459 Sw 18th Pl, Ocala, FL 34474	

[filter listings](#)

[Map](#) | 90 results

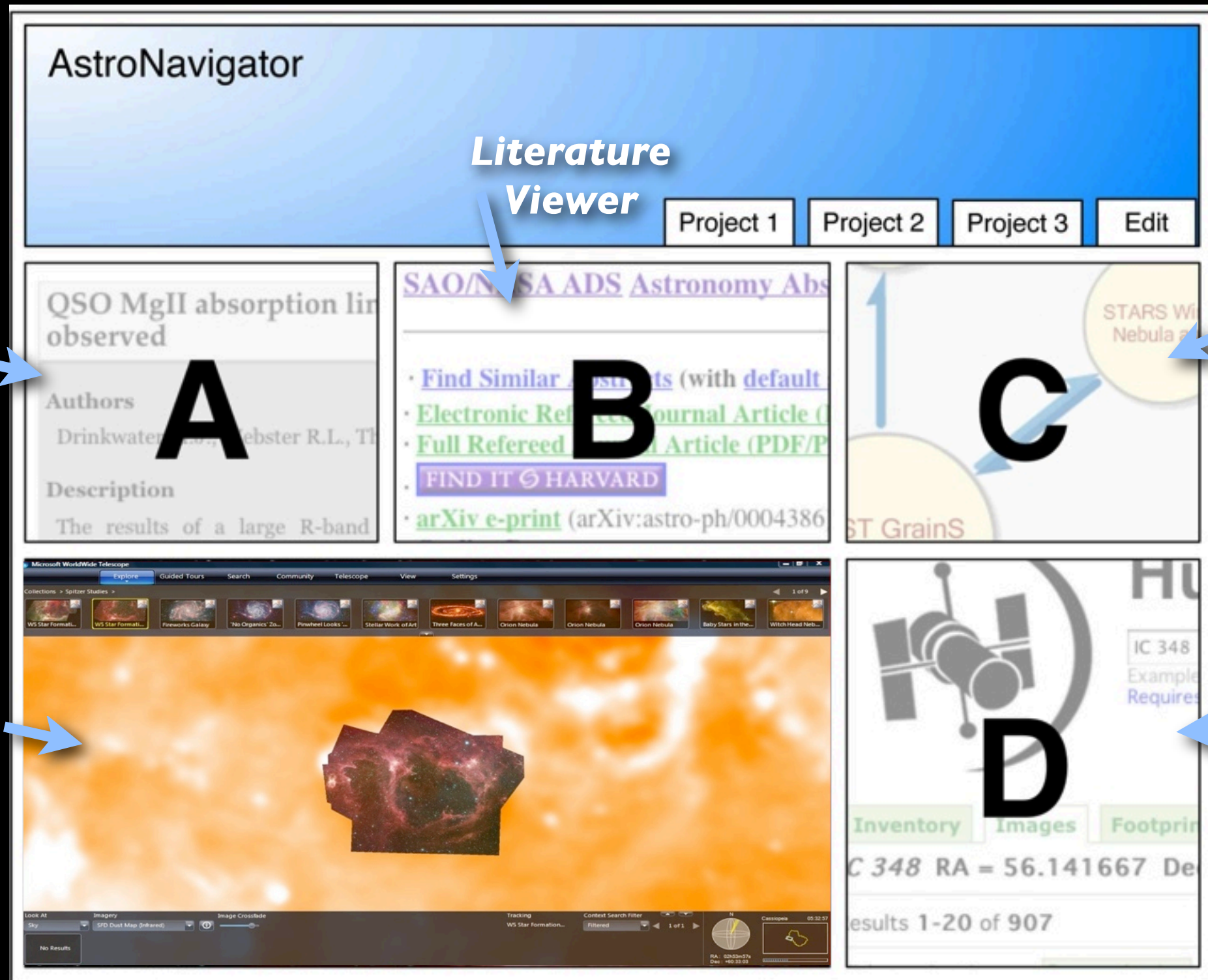
Banks

Regions Bank	352-291-2965
3101 Sw College Rd, Ocala, FL	
Regions Bank	352-861-2342
2811 Sw 27th Ave, Ocala, FL	
Wachovia Bank	352-873-5010
3201 Sw College Rd, Ocala, FL	
Community Bank & Trust of ...	352-369-1000
1603 Sw 19th Ave, Ocala, FL	

[Map](#) | 20 results



# Seamless Astronomy



Mockup based on work of Eli Bressert, excerpted from NASA AISRP proposal by Goodman, Muench, Christian, Conti, Kurtz, Burke, Accomazzi, McGuinness, Hendler & Wong, 2008



**“Ontology”**

**“GIS/Layering”**

**“Search”**

*What's needed?*

**“Progressive Resolve”**

**“Registration”**

**“Selection”**

**“Side-by-Side  
Comparison”**

**“Readable Labels”**

**“Highlighting”**

**“Zoom”**

**“Custom Site”**

**“Measurement”**

**“Off-the-Desktop”**

**“Inference”**



...and how to explain all  
that to the Astronomers?





Thursday, April 30, 2009



From: Yan Xu  
Subject: RE: (non WWT) press conference attendance for AG on Tuesday AM  
Date: December 31, 2008 2:56:23 AM EST  
To: Yan Xu , Alyssa Goodman , Megan Watzke  
Cc: Becki Culbert (Swift Group) , Curtis G. G. Wong <curtisgwong@msn.com> , Jens Kauffmann , Rosalind Reid

I just found Megan's earlier email, which mentioned that the press will be in room 204 of Convention Center. It is probably not too far from our room 308.

Our setup and presentation will be in the same room: #308 (Exhibition Hall C).

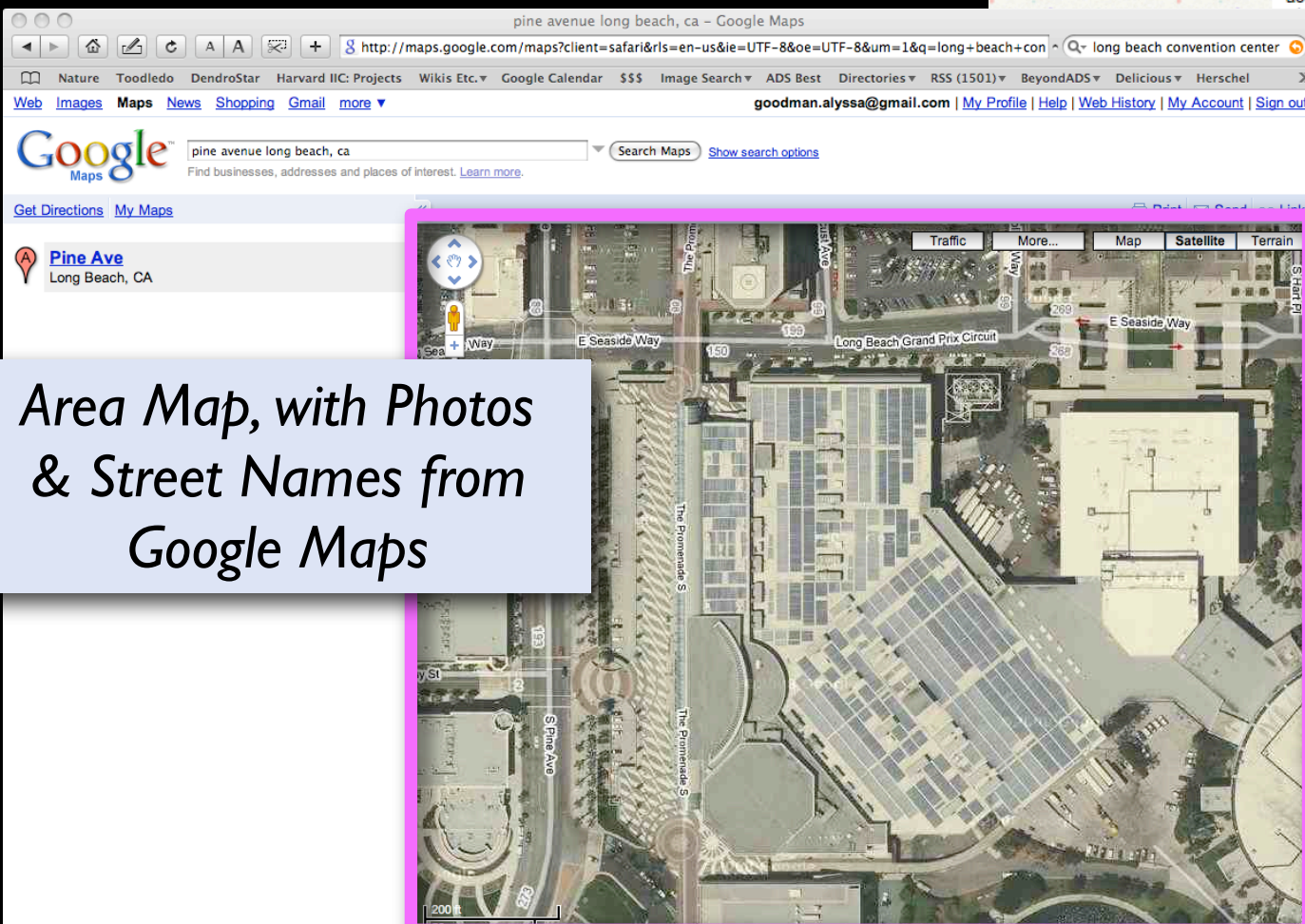
Thanks,  
Yan

Email with Room Numbers  
(result of search)

Requires “Ontology”

Interior Map on Long  
Beach CC Web Site

Requires “GIS/Layering”



Area Map, with Photos  
& Street Names from  
Google Maps

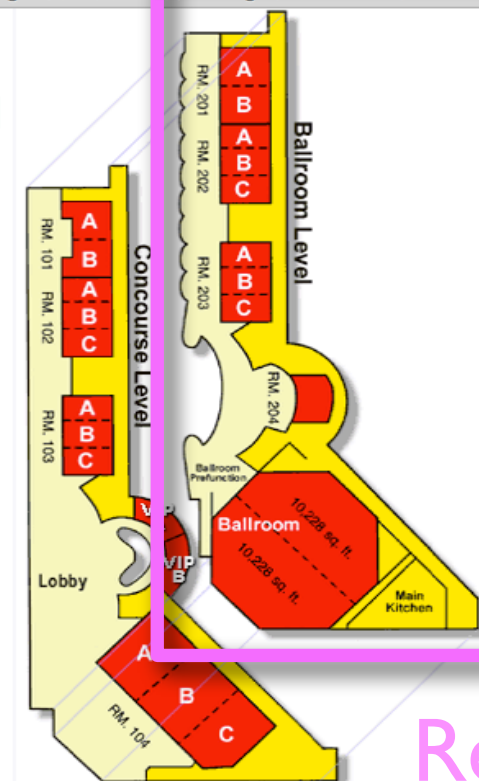
Ballroom & Meeting Room  
<http://www.longbeachcc.com/meeting.h>

#### SPECIAL SERVICES INCLUDED:

- House lighting, ventilation, heat or air conditioning as required during open times. Energy conservation is of prime concern to the Convention Center and minimal light and comfort levels will be maintained during move-in and move-out periods. Rehearsals and similar pre-event activities will be maintained accordingly.
- Housekeeping services during open hours in aisles, corridors, lobby, open spaces and restrooms, plus one thorough cleaning of these same areas during non-open hours. Meeting rooms will be cleaned between 12 AM and 1 PM nightly unless prior arrangements are made with the Event Manager.
- Water service will be supplied to head tables and rooms only. All other water service needs must be ordered through your Catering Sales Manager.
- The basic set up is included with the daily rental. Additional set ups are charged based upon half of the daily rental.
- Real-time basic room set per rented event day. Meeting rooms included with an Exhibit Hall rental include a one-basic room set for the run of the event.
- Fully equipped first-aid facilities. Does not include a first-aid kit. An Emergency Medical Technician will be scheduled through your Event Manager.
- Use of the outdoor marquee, as available. The marquee is not to be used for information directly related to Licensee's activities within the Convention Center. All messages must be pre-approved by Convention Center staff. (Please see the marketing kit for all in-house Marketing and Public Relations details pertaining to your event).

#### SPECIAL SERVICES NOT INCLUDED:

- First aid staffing with Emergency Medical Technician will be provided at current rates.
- Licensee is responsible for removal of bulk trash, crates, boxes, packing materials, lumber, etc. prior to show move-in and following move-out.
- Ticket sellers, ticket takers, ushers, security, stagehands, and event operations shall be provided by the Convention Center and billed to Licensee.
- Performance stages, exhibit tables and dance floors.



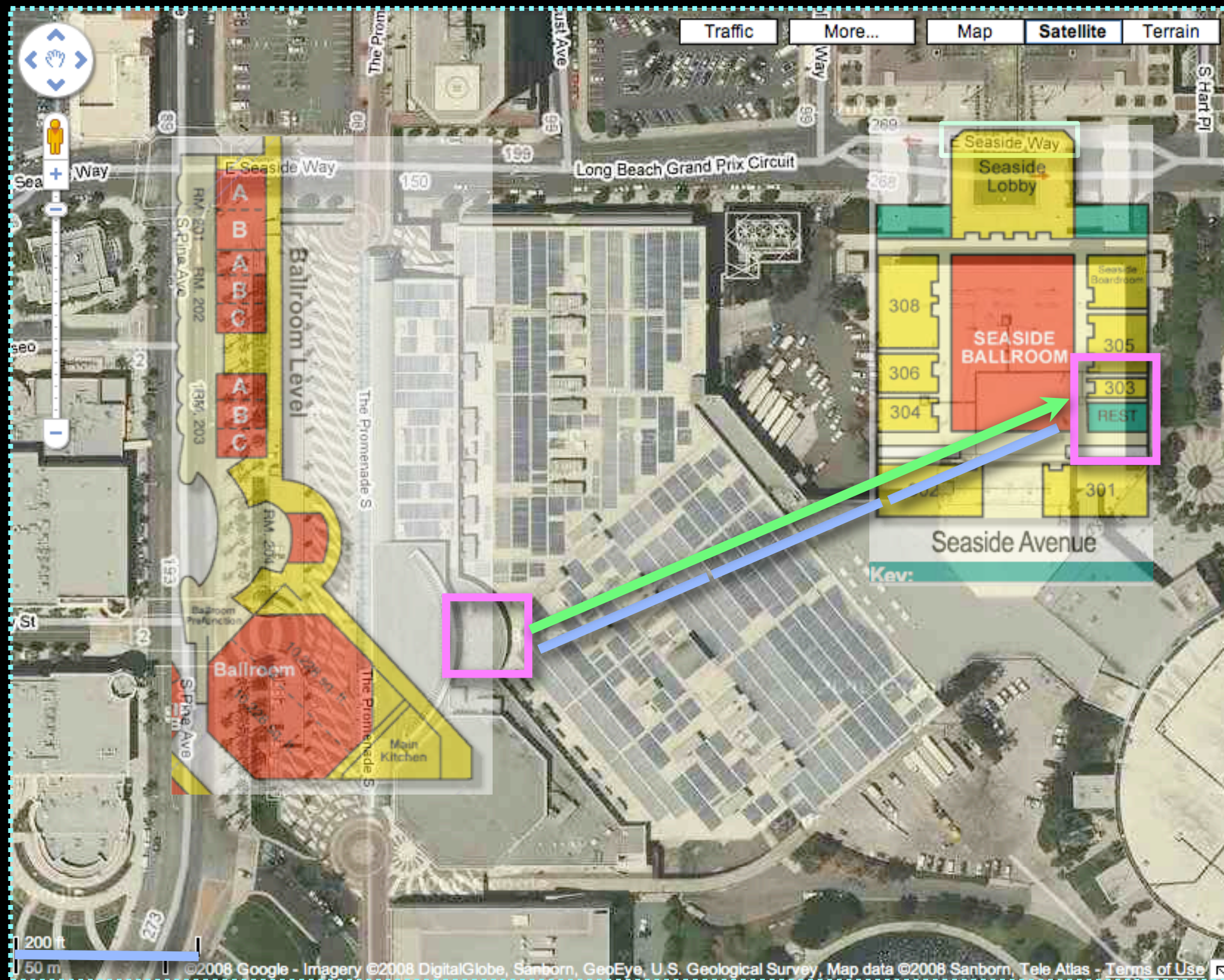
Requires  
“Search”



Seaside Avenue

Seaside Meeting Room Key:





...requires: **“Selection”** ; **“Registration”**;

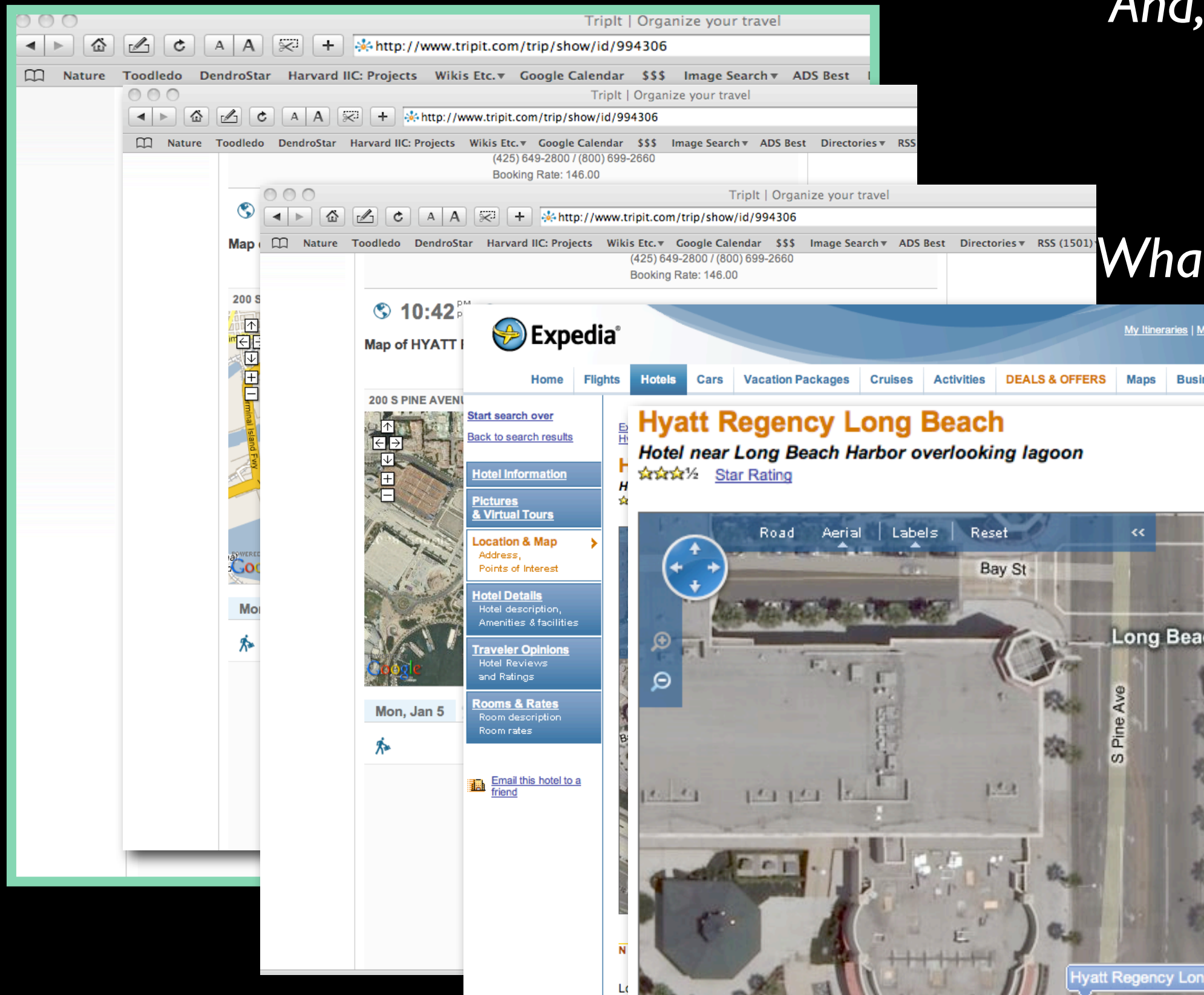
**“Readable Labels”** ; **“Highlighting”** ; & **“Measurement”**

in order to yield: **“Inference”**: ...Wow, that's about 600 feet, hope we can change the room!



And, what about that  
“**custom Triplt site**” I made to  
organize all this?

What about the hotel  
& its location?



Nearby Points of Interest









Over 20 million traveler reviews & opinions of hotels, vacations & more

My TripAdvisor Sign in

Register Now!

Hyatt Regency Long Beach Hotel

Home Destinations Fun & Games Free Travel Guides Vacation Ideas International Sites

Home → United States → California (CA) → Long Beach → Long Beach Hotels

## Search

 **Go**

Long Beach Overview

Long Beach Hotels

• **Hyatt Regency Long Beach**

Flights to Long Beach

Long Beach Deals

More On Long Beach

Before You Go

Things to Do

Restaurants

Map

Traveler Photos

Forum

Long Beach Deals

Discount Hotels

Hotel & Air

All Travel Offers

**Free Newsletter**

Interested in **Hyatt Regency Long Beach** and Long Beach?

We'll send you updates with the latest deals, reviews and articles for Hyatt



Hotel class: ★★★★★

Rooms: 510

**COMPARE PRICES**

[Hotel photos](#)

[Map this hotel](#)

[Hotel amenities](#)

[Virtual tour](#)

**200 South Pine Avenue, Long Beach, CA 90802**

**Property Type:** Hotel ?

Full service hotel with water views from rooms. Walking distance to 100 shops and restaurants, Aquarium of the Pacific. Centrally located for easy...

[more »](#)



**Check Rates and Availability: \$236** Avg. Price

Check-in:

10/2/2009

mm/dd/yyyy

Check-out:

10/9/2009

mm/dd/yyyy

Adults:

1

☒ Expedia.com

☒ LongBeach.Hyatt.com

☒ Travelocity

☒ Priceline.com

☒ Orbitz.com

☒ hotels.com

☐ HotelClub.com

☐ Gtahotels.com

**CHECK RATES!**

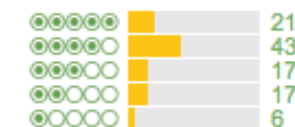
Opens one window for each offer. Please disable pop-up blockers.

**TripAdvisor Traveler Reviews**

TripAdvisor Traveler Rating:

**TripAdvisor Traveler Rating:** ?

104 Reviews



[Write a review](#)

**TripAdvisor Popularity Index:** ?

#14 of 38 hotels in Long Beach

**Call now to book: 1-800-45-HOTEL**  
from hotels.com

**Click here for best prices for Hyatt Regency Long Beach**

▶ [Hyatt Regency Long Beach: Great rooms from \\$115](#) **Smart Deal**  
[Expedia.com](#) Photos, Reviews and the Guaranteed Lowest Prices

▶ [Hyatt Regency Long Beach: Save Up To 50% On Hotels](#) **Smart Deal**  
[Orbitz.com](#) View Hotel Photos, Reviews & More Compare & Save on Hotels at Orbitz

▶ [Hyatt Regency Long Beach: Official Site](#) **Smart Deal**  
[LongBeach.Hyatt.com](#) Best Rates Guaranteed. Book Direct.

▶ [Hyatt Regency Long Beach: Official Site.](#) **Smart Deal**  
[Hyatt Regency Long Beach](#) Best Rates



# *What's possible now?*

**“Progressive Resolve”**

**“Zoom”**

**“Search”**

**“Selection”**

**“GIS/Layering”**

**“Registration”**

**“Side-by-Side  
Comparison”**

**“Readable Labels”**

**“Highlighting”**

**“Custom Site”**

**“Inference”**

**“Off-the-Desktop”**


**“Ontology”**

**“Measurement”**



Image ssc2003-06f

http://www.spitzer.caltech.edu/Media/releases/ssc2003-06/ssc2003-06f Google

**Spitzer Space Telescope**

• Jet Propulsion Laboratory  
• California Institute of Technology  
• Vision for Space Exploration

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- Fast Facts
- Press Kit (.pdf)
- Fact Sheet (.pdf)
- Field Guides
- Glossary

**Media Contacts**

INTRODUCTIONPRESS RELEASEVISUALSQUICK FACTS



**Embedded Outflow in HH 46/47** **Spitzer Space Telescope • IRAC**  
Inset: visible light (DSS) ssc2003-06f

NASA / JPL-Caltech / A. Noriega-Crespo (SSC/Caltech)

Credit: NASA/JPL-Caltech/A. Noriega-Crespo (SSC/Caltech), Digital Sky Survey

## HH46/47

This image from NASA's Spitzer Space Telescope transforms a dark cloud into a silky translucent veil, revealing the molecular outflow from an otherwise hidden newborn star. Using near-infrared light, Spitzer pierces through the dark cloud to detect the embedded outflow in an object called HH 46/47. Herbig-Haro (HH) objects are bright, nebulous regions of gas and dust that are usually buried within dark clouds. They are formed when supersonic gas ejected from a forming protostar, or embryonic star, interacts with the surrounding interstellar medium. These young stars are often detected only in the infrared.

The Spitzer image was obtained with the infrared array camera. Emission at 3.6 microns is shown as blue, emission from 4.5 and 5.8 microns has been combined as green, and 8.0 micron emission is depicted as red.

HH 46/47 is a striking example of a low-mass protostar ejecting a jet and creating a bipolar, or two-sided, outflow. The central



## HH4647

[ADD NOTE](#) [SEND TO GROUP](#) [ADD TO SET](#) [BLOG THIS](#) [ALL SIZES](#) [ORDER PRINTS](#) [ROTATE](#) [EDIT PHOTO](#) [DELETE](#)

Embedded Outflow in HH 46/47

Spitzer Space Telescope • IRAC

NASA / JPL-Caltech / A. Noriega-Crespo (SSC/Caltech)

Inset: visible light (DSS)  
ssc2003-06f

“Search”

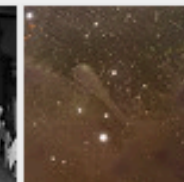
“Custom Site”

“Registration”

“Readable Labels”

Uploaded on January 6, 2009  
by [Alyssa Goodman](#)

## Alyssa\_Goodman's photostream

16  
uploads[browse](#)

This photo also belongs to:

[astrometry \(Pool\)](#) x

## Tags

- [Astrometrydotnet:version=10145](#) x
- [Astrometrydotnet:id=alpha-200901-20629873](#) x
- [Astrometrydotnet:status=solved](#) x

[Add a tag](#)

## Additional Information

- All rights reserved ([edit](#))
- Anyone can see this photo ([edit](#))
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- Viewed 7 times (Not including you)
- [Edit title, description, and tags](#)

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# WWT Silverlight “Alpha”

The screenshot displays the Microsoft WorldWide Telescope Web Client interface. The main window shows a deep space image of the HH4647 nebula. The interface includes a top navigation bar with links like 'Explore', 'Guided Tours', 'Search', 'Community', 'View', and 'Settings'. A left sidebar shows a 'Collections' pane with 'Open Collections' and 'HH4647'. The bottom control panel includes 'Look At' (Sky), 'Imagery' (Digitized Sky Survey (Optical)), 'Image Crossfade', a 'Vela' map, a 'Bubbly Little Star' thumbnail, a compass, and coordinates (RA: 08h25m38s, Dec: -51:01:43). A 'Done' button is at the bottom left. Several text labels are overlaid on the image to highlight features: 'Progressive Resolve', 'Zoom', 'Search', 'Selection', 'GIS/Layering', 'Registration', 'Side-by-Side Comparison', 'Readable Labels', 'Highlighting', 'Custom Site', and 'Inference'.

Progressive Resolve

Zoom

Search

Selection

GIS/Layering

Registration

Side-by-Side Comparison

Readable Labels

Highlighting

Custom Site

Inference



# *And to go fully “seamless”?*

**“Progressive Resolve”**

**“Zoom”**

**“Search”**

**“Selection”**

**“GIS/Layering”**

**“Registration”**

**“Side-by-Side  
Comparison”**

**“Readable Labels”**

**“Highlighting”**

**“Custom Site”**

**“Inference”**

**“Off-the-Desktop”**

**“Ontology”**

**“Measurement”**



# Going “Off-the-Desktop”



Microsoft  
Surface

More information: See the IIC's  
“Scientists Discovery Room” [project pages](#)

## Slideshow: Tabletop Computers *Continued*

By Meredith Ringel Morris

First Published December 2008

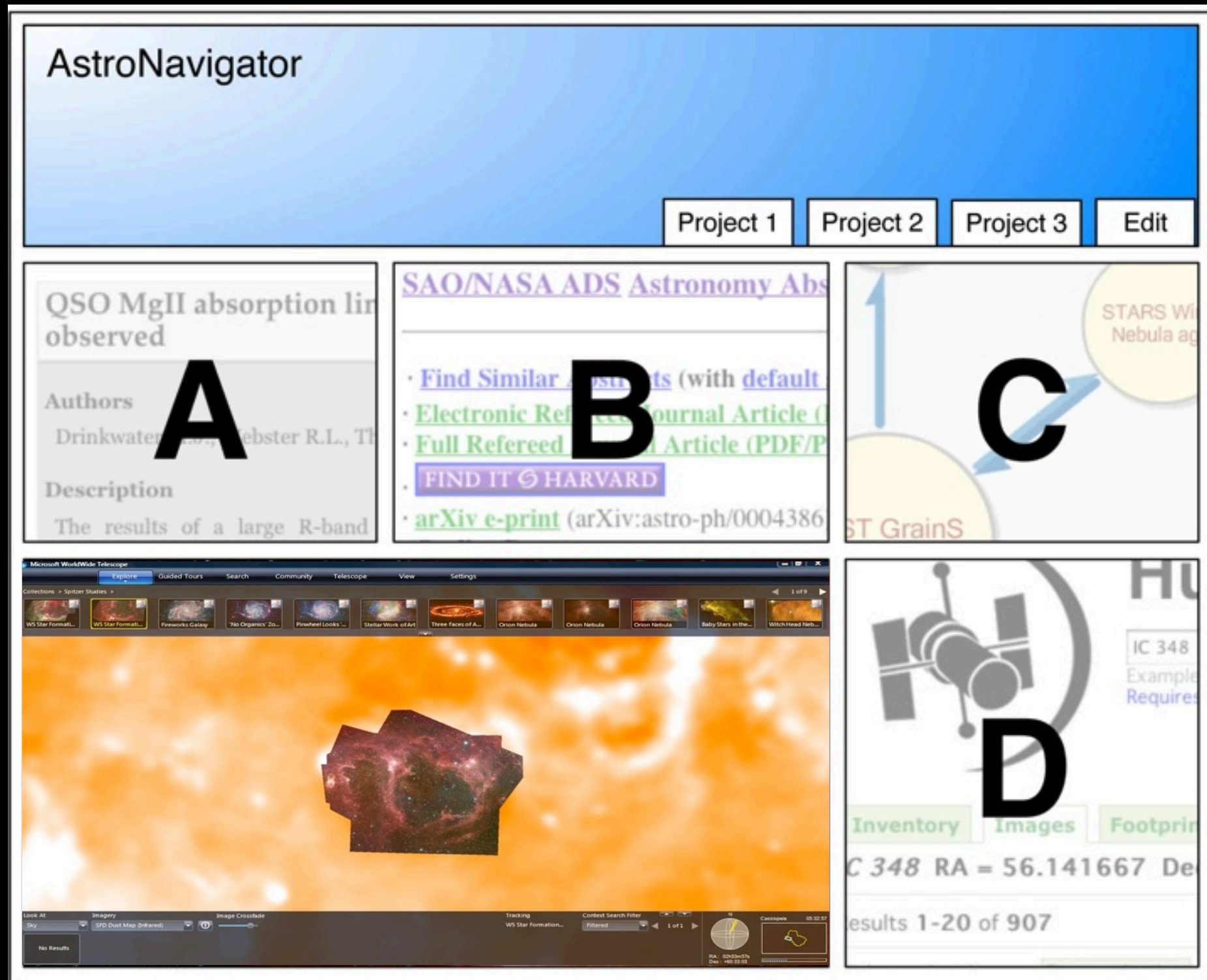
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**UBITABLE:** Users can interact with surface computers through auxiliary devices, such as laptops, phones, and PDAs. The display on the auxiliary device can convey private or sensitive content to a single user, while group-appropriate content can appear on the tabletop display. Chia Shen and her colleagues at Mitsubishi Electric Research Laboratories, in Cambridge, Mass., have explored auxiliary interactions with surface computers in their UbiTable project, in which two people with laptops collaborate over a tabletop display. Recently, Shen expanded the UbiTable into an interactive room called the WeSpace. People can share data on their laptops with other people in the room, using both a table and a large display wall. Here, three Harvard University astrophysicists discuss radio and IR spectrum images using the WeSpace.



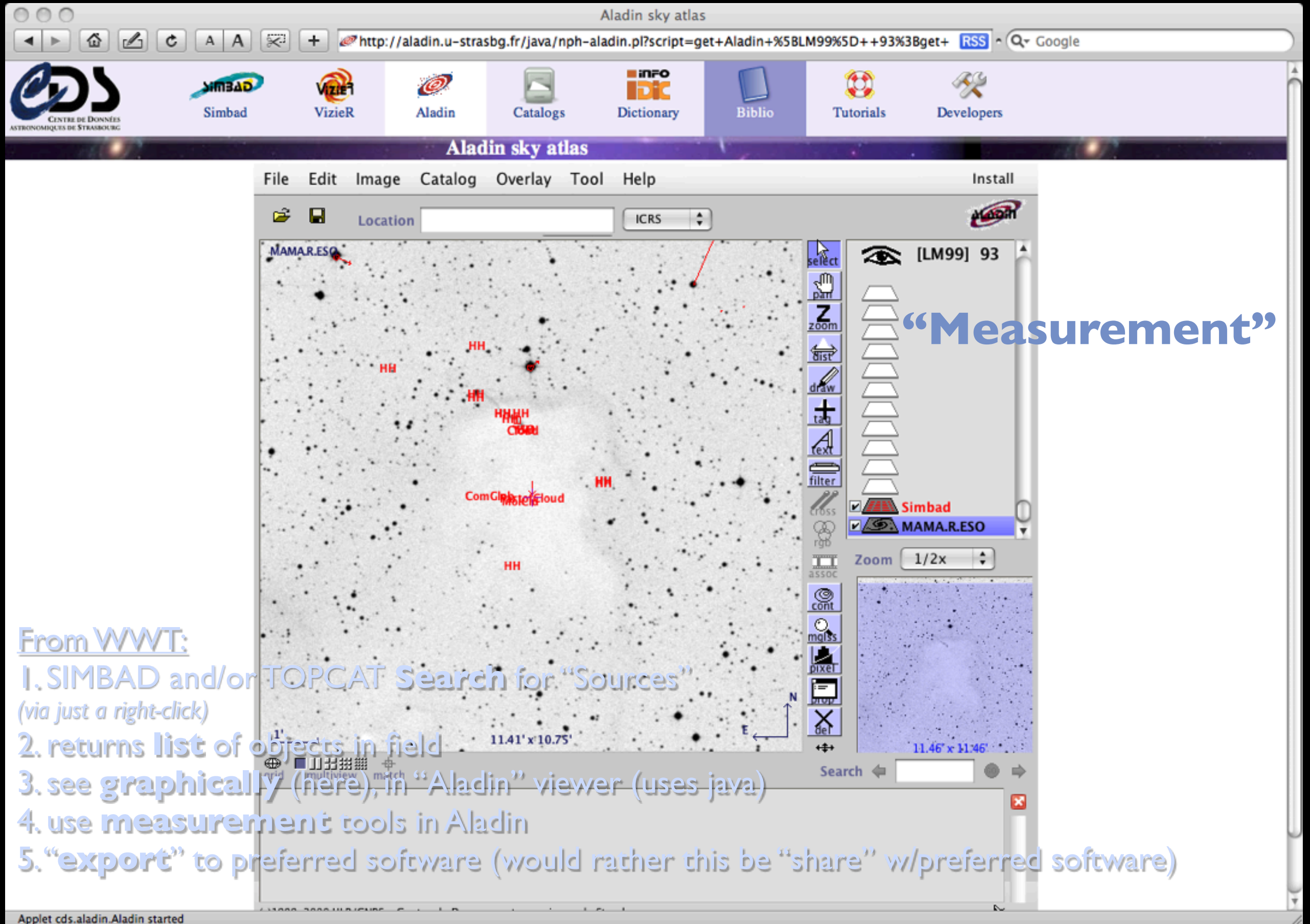
# “Ontology” “Measurement” Seamless Astronomy



Mockup based on work of Eli Bressert, excerpted from NASA AISRP proposal by Goodman, Muench, Christian, Conti, Kurtz, Burke, Accomazzi, McGuinness, Hendler & Wong, 2008







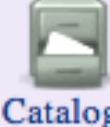




# Sharing Amongst Applications





SIMBAD query result

http://simbad.u-strasbg.fr/simbad/sim-coo?CooE RSS Google

**SIMBAD query result**

*other query modes :* [Identifier query](#) [Coordinate query](#) [Criteria query](#) [Bibliography query](#) [Basic query](#) [Script submission](#) [Output options](#) [Help](#)

Object query : coord 3.44989898784776h+30.3468458710566d  
(FK5, 2000, 2000), radius: 10 arcmin

C.D.S. - SIMBAD4 rel 1.114 - 2000.03.27CET16:11:40

Number of objects : 29 [plot this list of objects](#) ☒ Equat. ☐ Gal ☐ SGal ☐ Ecl

in either Aladin (default...ugly...but quantitative) or WWT (via SAMP)

N	Identifier	dist(asec)	Otype	ICRS (2000) coord.	Sp type	#ref 1850 - 2009	#notes
1	<a href="#">HH 279A</a>	82.46	HH	03 26 57.1 +30 19 33	~	1	0
2	<a href="#">HH 279B</a>	127.83	HH	03 26 59.1 +30 18 41	~	1	0
3	<a href="#">HH 278C</a>	289.57	HH	03 27 02.4 +30 25 36	~	1	0
4	<a href="#">HH 278</a>	309.37	HH	03 26 59.4 +30 25 58	~	5	0
5	<a href="#">HH 278A</a>	309.37	HH	03 26 59.4 +30 25 58	~	1	0
6	<a href="#">HH 278B</a>	314.55	HH	03 27 00.5 +30 26 03	~	1	0
7	<a href="#">HH 279</a>	324.83	HH	03 27 18.6 +30 17 16	~	4	0
8	<a href="#">HH 279C</a>	325.81	HH	03 27 18.7 +30 17 16	~	1	0
9	<a href="#">[EYG2006] Bolo 19</a>	342.02	mm	03 27 02.0 +30 15 08	~	2	0
10	<a href="#">HH 493</a>	378.13	HH	03 26 49.3 +30 14 55	~	4	0
11	<a href="#">[JHE2006] J032649+301454</a>	380.46	IR	03 26 49.0 +30 14 54	~	1	0
12	<a href="#">HH 317D</a>	400.22	HH	03 26 56.9 +30 14 10	~	1	0
13	<a href="#">TXS 0323+301</a>	405.25	Rad	03 26 32.9 +30 17 18	~	0	0



# Prototype “Faceted” Browsing

(using very lightweight “**Ontology**”)

Faceted browsing of the IVOA Registry

[Start search](#)

2 filter criteria [\(remove all\)](#)

- Wavelength coverage: Infrared [\(remove\)](#) [\[add more\]](#)
- Text Search: "quasar" [\(remove\)](#)

Order Commands

40 items  
sorted by Citation [A to Z]

1(28) 2(12)

« previous 1 2 3 4 next »

### QSO MgII absorption line systems (Drinkwater+, 1993) - Quasars observed

**Authors**  
Drinkwater M.J., Webster R.L., Thomas P.A.

**Description**  
The results of a large R-band imaging survey of 71 bright ( $m(V) < 18$ ) quasars are presented. The quasars were chosen from published samples which have intermediate resolution optical spectroscopy available, so the presence of low redshift Mg II absorption lines can be determined. We have searched our data for galaxies close to the line-of-sight to the quasars, which we might be able to identify with the absorption systems. We find a high coincidence between galaxies very near the line-of-sight and quasars showing absorption systems in their spectra, a result consistent with other studies. These galaxies have a mean luminosity of  $0.5L_{\text{star}}$  (assuming they lie at the absorption redshift). The distribution of impact parameters between the galaxies and the quasars extends with a flat distribution to large radii ( $> 30h^{-1}\text{kpc}$ ). This suggests that the absorption systems may not be gravitationally bound to the observed galaxies, but may be part of larger extended systems. We also find a significant number of galaxies near the line-of-sight to the

**Type**  
Catalog

**Content Level**  
Research

**VizieR collection**  
[Tables from Astronomical Journal](#)

**Bibliographic Code**  
[1993AJ....106..848D](#)

**Original data**  
[\[external link\]](#)

Type here to search

⌵ VizieR keyword

Type here to filter

- QSOs (35)
- Redshifts (9)
- Wide-band photometry (9)
- Spectroscopy (6)
- Galaxies (4)
- Photometry (3)
- White Dwarf stars (3)

⌵ Wavelength coverage

Type here to filter

- Radio (16)
- Optical (15)
- UV (13)
- X-ray (13)

⌵ VizieR catalog collection

Type here to filter

- Tables from Astronomical Journal (16)
- Tables from Astrophysical Journal Supplement Series (13)
- Tables from Astronomy and Astrophysics Supplement Series (6)

*courtesy Douglas Burke, CfA/IIC*



# We need to catch up to this & go beyond...

The image displays three overlapping web browser windows from the year 2009, illustrating a digital footprint or travel planning process.

**Top Window: Facebook Profile**  
The browser shows the Facebook profile of Nicholas Suntzeff. The address bar indicates the URL: <http://www.facebook.com/profile.php?id=1438935116&ref=nf>. The profile picture shows a man with glasses. The bio states: "Nicholas Suntzeff is in long beach, amazed at the number of smart, young astronomers. 12 hours ago". Navigation tabs include Wall, Info, Photos, and Boxes.

**Middle Window: TerabitZ Real Estate**  
The TerabitZ website is shown with the tagline "every bit on real estate". The search bar is set to "Ocala, FL". Below the search bar are various service icons: Local Search, Local Photos, Airports, Banks, Cafes, Cinemas, Fast Food, Gas Stations, Grocery Stores, Health Care, and Libraries. A "Mini Map" shows the Ocala area. Two columns of "For Sale Listings" are visible, with properties ranging from \$49,900 to \$150,000. A "Banks" section lists local financial institutions like Regions Bank and Wachovia Bank.

**Bottom Window: Triplt Travel Itinerary**  
The Triplt website shows a travel itinerary for a trip to Los Angeles and Long Beach, CA. The itinerary includes:  
- A flight from Los Angeles, CA, arriving at 9:42 PM PST.  
- A stay at the HYATT REGENCY LONG BEACH, Long Beach, CA, from 10:32 PM PST to 1:50 PM PST (4 nights).  
- A meeting titled "AAS Meeting" on Monday, Jan 5, in Long Beach, CA.  
The itinerary also includes booking information, such as the booking reference # TWXDPC and the booking rate of 146.00.



# Opportunities for Progress: Generalizing “Semantic” (Life) Science

“SCF”:

Loading "SWAN Hypothesis Browser"

http://hypothesis.alzforum.org/swan/doIgetHome.action

swan clark neuro

**SWAN Alzheimer Knowledge Base** beta

Semantic Web Applications in Neuromedicine

Log in to browse the SWAN Alzheimer Knowledgebase | [SWAN Terms of Use](#)

Home About

## Welcome to the SWAN Alzheimer Knowledge Base


SWAN is the participatory knowledge base of Alzheimer Disease that YOU can help develop. SWAN is all about how you interpret, debate, ask questions and advance the science.

Log in now to browse the SWAN Alzheimer Knowledgebase!


**Login Now!**

Or [Contact us](#) if you are interested in participating to our Beta Program!

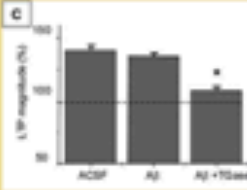
### » Featured Contributions



**H** [Aβ Plaques Lead to Aberrant Regulation of Calcium Homeostasis In Vivo Resulting in Structural and Functional Disruption of Neuronal Networks.](#)  
Kuchibhotla Kishore V et Al.



**H** [Amyloid-β protein dimers isolated directly from Alzheimer's brains impair synaptic plasticity and memory](#)  
Shankar Ganesh M et Al.



**H** [Transglutaminase induces proteolytic amyloid β-protein assemblies that are resistant and inhibit long-term potentiation](#)  
Hartley Dean M et Al.

*click on the title to browse the full content and use the arrows to scroll the list*

### » Hot Topics (browse all hypotheses)

- Aβ accumulation in the brain is the primary event in Alzheimer Disease pathogenesis
- Soluble oligomeric aggregates of Aβ are toxic to neurons and cause AD pathology
- Insoluble fibrillar Aβ leads to AD
- Defective mechanisms of Aβ clearance contribute to AD
- Tau dysfunction mediates neurodegeneration
- ApoE contributes to AD through multiple mechanisms
- Changes in calcium homeostasis may provide a common pathway for the neuropathological changes in AD
- Changes in presenilin function lead to dementia and neurodegeneration in Alzheimer Disease
- Misfolded proteins accumulated into protein aggregates characterizes the pathologic lesions of AD
- The molecular mechanisms of neuronal cell death are involved in the dysfunction and death of neurons in AD
- Synaptic loss appears to be the most powerful and ubiquitous proximate factor leading to the dementia of AD
- Failure of axonal transport might be the underlying basis for neurodegeneration in AD
- Cell membrane properties play a key role in AD Pathophysiology

### » Mechanisms

- Energetics
- Functional Changes of Proteins
- Structural Changes of Proteins

### » How to Contribute

- **Build a hypothesis**
- **Critique a hypothesis**
- **Nominate a key paper**
- **Help find connections**
- **Propose new features**
- **Add supporting evidence**

[Contact us!](#)

### » Knowledge Base

**Statements**  
1438 Research Statements  
» 128 [Hypotheses](#)  
» 26 with Extended annotation  
» 102 with Simple annotation  
» 1310 Claims  
35 [Research Questions](#)  
29 [Comments](#)

**Publications**  
1201 Journal Articles  
6 Journal Comments  
2 Journal News  
30 Web Comments

Loading "http://hypothesis.alzforum.org/swan/doIgetHome.action", completed 86 of 89 items

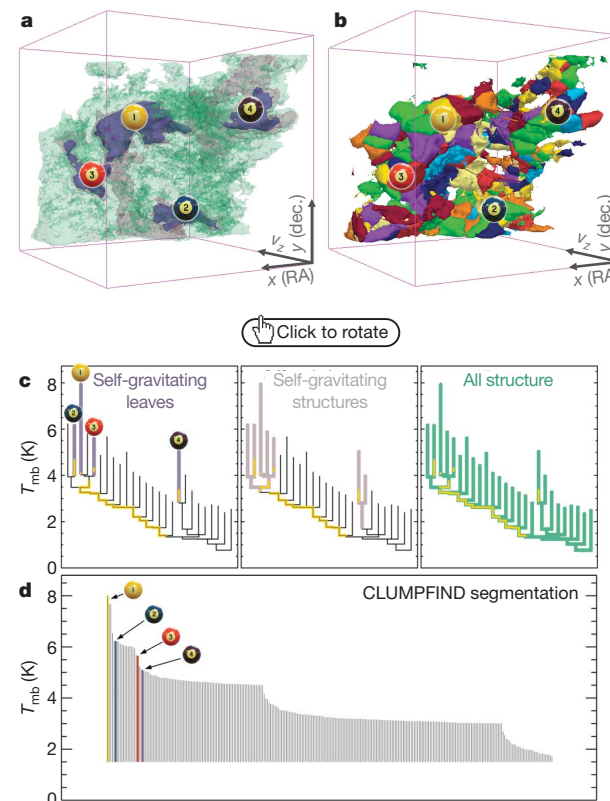


# Progress (on the “beyond” bit)!

## 3D PDF



Goodman et al.  
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**Figure 2 | Comparison of the ‘dendrogram’ and ‘CLUMPFIND’ feature-identification algorithms as applied to  $^{13}\text{CO}$  emission from the L1448 region of Perseus.** **a**, 3D visualization of the surfaces indicated by colours in the dendrogram shown in **c**. Purple illustrates the smallest scale self-gravitating structures in the region corresponding to the leaves of the dendrogram; pink shows the smallest surfaces that contain distinct self-gravitating leaves within them; and green corresponds to the surface in the data cube containing all the significant emission. Dendrogram branches corresponding to self-gravitating objects have been highlighted in yellow over the range of  $T_{\text{mb}}$  (main-beam temperature) test-level values for which the virial parameter is less than 2. The  $x$ - $y$  locations of the four ‘self-gravitating’ leaves labelled with billiard balls are the same as those shown in Fig. 1. The 3D visualizations show position–position–velocity ( $p$ - $p$ - $v$ ) space. RA, right ascension; dec., declination. For comparison with the ability of dendrograms (**c**) to track hierarchical structure, **d** shows a pseudo-dendrogram of the CLUMPFIND segmentation (**b**), with the same four labels used in Fig. 1 and in **a**. As ‘clumps’ are not allowed to belong to larger structures, each pseudo-branch in **d** is simply a series of lines connecting the maximum emission value in each clump to the threshold value. A very large number of clumps appears in **b** because of the sensitivity of CLUMPFIND to noise and small-scale structure in the data. In the online PDF version, the 3D cubes (**a** and **b**) can be rotated to any orientation, and surfaces can be turned on and off (interaction requires Adobe Acrobat version 7.0.8 or higher). In the printed version, the front face of each 3D cube (the ‘home’ view in the interactive online version) corresponds exactly to the patch of sky shown in Fig. 1, and velocity with respect to the Local Standard of Rest increases from front ( $-0.5 \text{ km s}^{-1}$ ) to back ( $8 \text{ km s}^{-1}$ ).

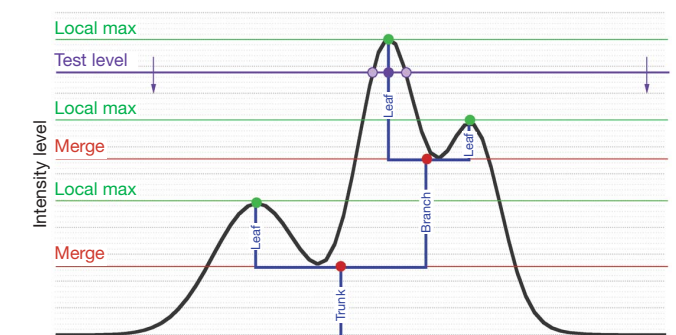
data, CLUMPFIND typically finds features on a limited range of scales, above but close to the physical resolution of the data, and its results can be overly dependent on input parameters. By tuning CLUMPFIND’s two free parameters, the same molecular-line data set<sup>8</sup> can be used to show either that the frequency distribution of clump mass is the same as the initial mass function of stars or that it follows the much shallower mass function associated with large-scale molecular clouds (Supplementary Fig. 1).

Four years before the advent of CLUMPFIND, ‘structure trees’<sup>9</sup> were proposed as a way to characterize clouds’ hierarchical structure

using 2D maps of column density. With this early 2D work as inspiration, we have developed a structure-identification algorithm that abstracts the hierarchical structure of a 3D ( $p$ - $p$ - $v$ ) data cube into an easily visualized representation called a ‘dendrogram’<sup>10</sup>. Although well developed in other data-intensive fields<sup>11,12</sup>, it is curious that the application of tree methodologies so far in astrophysics has been rare, and almost exclusively within the area of galaxy evolution, where ‘merger trees’ are being used with increasing frequency<sup>13</sup>.

Figure 3 and its legend explain the construction of dendrograms schematically. The dendrogram quantifies how and where local maxima of emission merge with each other, and its implementation is explained in Supplementary Methods. Critically, the dendrogram is determined almost entirely by the data itself, and it has negligible sensitivity to algorithm parameters. To make graphical presentation possible on paper and 2D screens, we ‘flatten’ the dendrograms of 3D data (see Fig. 3 and its legend), by sorting their ‘branches’ to not cross, which eliminates dimensional information on the  $x$  axis while preserving all information about connectivity and hierarchy. Numbered ‘billiard ball’ labels in the figures let the reader match features between a 2D map (Fig. 1), an interactive 3D map (Fig. 2a online) and a sorted dendrogram (Fig. 2c).

A dendrogram of a spectral-line data cube allows for the estimation of key physical properties associated with volumes bounded by isosurfaces, such as radius ( $R$ ), velocity dispersion ( $\sigma_v$ ) and luminosity ( $L$ ). The volumes can have any shape, and in other work<sup>14</sup> we focus on the significance of the especially elongated features seen in L1448 (Fig. 2a). The luminosity is an approximate proxy for mass, such that  $M_{\text{lum}} = X_{13\text{CO}} L_{13\text{CO}}$ , where  $X_{13\text{CO}} = 8.0 \times 10^{20} \text{ cm}^{-2} \text{ K}^{-1} \text{ km}^{-1} \text{ s}$  (ref. 15; see Supplementary Methods and Supplementary Fig. 2). The derived values for size, mass and velocity dispersion can then be used to estimate the role of self-gravity at each point in the hierarchy, via calculation of an ‘observed’ virial parameter,  $\alpha_{\text{obs}} = 5\sigma_v^2 R / GM_{\text{lum}}$ . In principle, extended portions of the tree (Fig. 2, yellow highlighting) where  $\alpha_{\text{obs}} < 2$  (where gravitational energy is comparable to or larger than kinetic energy) correspond to regions of  $p$ - $p$ - $v$  space where self-gravity is significant. As  $\alpha_{\text{obs}}$  only represents the ratio of kinetic energy to gravitational energy at one point in time, and does not explicitly capture external over-pressure and/or magnetic fields<sup>16</sup>, its measured value should only be used as a guide to the longevity (boundedness) of any particular feature.



**Figure 3 | Schematic illustration of the dendrogram process.** Shown is the construction of a dendrogram from a hypothetical one-dimensional emission profile (black). The dendrogram (blue) can be constructed by ‘dropping’ a test constant emission level (purple) from above in tiny steps (exaggerated in size here, light lines) until all the local maxima and mergers are found, and connected as shown. The intersection of a test level with the emission is a set of points (for example the light purple dots) in one dimension, a planar curve in two dimensions, and an isosurface in three dimensions. The dendrogram of 3D data shown in Fig. 2c is the direct analogue of the tree shown here, only constructed from ‘isosurface’ rather than ‘point’ intersections. It has been sorted and flattened for representation on a flat page, as fully representing dendrograms for 3D data cubes would require four dimensions.



A very radical proposal for  
how to get this all done...

